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THE APPLICATION OF THE TOTAL SYSTEMS APPROACH TO FACTORY PRODUCED DWELLINGS FOR THE LOW-TO-MEDIUM INCOME FAMILY

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF MECHANICAL ENGINEERING

EDMONTON, ALBERTA

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The undersigned certify that they have read and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "THE APPLICATION OF THE TOTAL SYSTEMS APPROACH TO FACTORY PRODUCED DWELLINGS FOR THE LOW-TO-MEDIUM INCOME FAMILY" submitted by HIROYOSHI HAYASHI in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

This thesis has developed and designed a functional housing system referred to as the FLEXI-GROW housing system that is priced to meet the demand of the low-to-medium income family.

The results of the study show that the function of the FLEXI-GROW housing system can be accomplished by using prefabricated load bearing panels, which are assembled using a specially designed locking mechanism.

Special emphasis has been placed on the design of a manufacturing facility to produce the housing panels.

ACKNOWLEDGEMENTS

The author would like to express his appreciation to Dr. J.C. Sprague for his guidance and supervision. Thanks are due also to Mrs. Carol Reed for typing this thesis.

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CHAPTER I

INTRODUCTION

By the year 2000, the total number of residential dwellings in the world will likely be double that of today. This will result from the growth of the world's population from the present figure of 4 billion to 6.5 billion over the next 30 years. [1]

Canada is faced with building approximately 2,500,000 new dwellings in the coming decade to meet our housing needs. There is a need within the building industry and the government to develop modern techniques and new materials in order to overcome the high cost and shortage of housing. The problem is becoming serious due to the fact that the rising cost of residential dwellings in the country has reached the point where the cost of a residential dwelling may soon be out of the reach of the average income family.

All phases of the housing problem should be fully studied from the standpoint of planning, programming, design, production, and construction in order to meet the increasing demand and contribute to the welfare of society.

This study is an extension of the work conducted in the department (see foot note) and aimed at developing a housing system to help alleviate the housing problem for low-to-medium income families.

CHOE, J., "The Design of FLEXI-GROW Housing System", The Department of Mechanical Engineering, University of Alberta, 1973.

The approach pursued is to design homes with enough flexibility to expand and change with the families' requirements. It is referred to as the FLEXI-GROW housing system. This system allows the family to start with a small house and expand it economically as desired. The house has been designed to meet the changing demands of the owner and to keep the initial investment and monthly payments to a minimum.

In this study, these objectives have been accomplished through applying the total systems approach to the design and production in order to reduce the material and manufacturing cost and to shorten the erection time on-site to a major degree. The design utilizes plastics and steel, relatively new materials to the housing industry. These materials and the dwelling plans which are developed and designed in this study allow much closer tolerances than can economically be maintained with wood making factory production a reality. Combining these factors with lower wage rates than conventional construction, additional savings in large quantity purchases of the materials and efficient manpower utilization allow a single family dwelling to be constructed with reasonable flexibility at a lower cost than most present methods of construction.

CHAPTER II

FLOOR PLAN DEVELOPMENT

The development of the FLEXI-GROW housing system is dependent on a basic floor plan that can be readily expanded to accommodate any size family.

2.1 An Acceptable Module for Design

1. The module determines the measurement upon which an architectural desian is based.
2. The module determines the exact dimensions of each building component.
3. The module determines the position of the building components within the system and within the building itself.

Due to its convenience, the modular concept accepted by most countries in the world is either in centimeters or inches. In 1959, the Housing Committee of the European Economic Commission agreed on the basic module of 10 centimeters. This was a decision of fundamental importance, which also corresponded to the Anglo-American measurement of 4 inches, approximately 10 centimeters, and 1 foot, approximately 30 centimeters. The Soviet Union had previously introduced the basic module of 10 centimeters in 1954.

Canada will likely eventually change to the metric system. Therefore, the chosen basic module for the FLEXI-GROW housing system is four inches, which can easily be converted to 10 centimeters.

2.2 Lot Size

The standard residential lot sizes are usually determined by local and provincial regulations. For example, in Alberta they are

determined by Alberta Regulation 215/67, The Subdivision and Transfer Regulation.

According to this, the Province has defined lots for single family homes as being a minimum of 5,000 square feet with a mean length of at least 100 feet and a mean width of at least 40 feet. In those subdivisions where no roadway and utility right-of-way (i.e. lanes) exist, lots must be a minimum of 5,500 square feet with a mean width of at least 55 feet and a length of not less than 100 feet.

The typical residential lot size provided by the City of Edmonton is 50 feet to 60 feet by 110 feet. The city is going to change the regulation on minimum lot size requirement to obtain more flexibility in planning. However, the short side of the lot will remain at 50 feet to 60 feet.

Therefore a lot size of 50 feet by 110 feet was used in this design project to develop the floor plans for the FLEXI-GROW housing system.

2.3 The Basic Floor Plan and Its Expansion

Average ages of brides and bridegrooms for first marriages are 22 and 25, respectively [2]. The average age of the NHA, (National Housing Act), borrower is 33 years, and the borrower has, on the average, two children [3]. Using this data as a basis the initial floor plan was developed to provide two bedrooms, a living room, a dinette, a kitchen and a bathroom.

The initial floor plan has 720 square feet, (24 feet by 30 feet). This provides the following areas:

	Room	Square Feet
(1)	Master bedroom	144
(2)	Second bedroom	96
(3)	Living room	172
(4)	Dinette	48
(5)	Kitchen	80
(6)	Three closets	34
(7)	Bathroom	48
(8)	Hallway	98
Total Area		720 square feet

The details of the initial floor plan and some possible expansions are shown in Figure 2.1, 2.2 and 2.3. Other alternative floor plans are included in Appendix A.

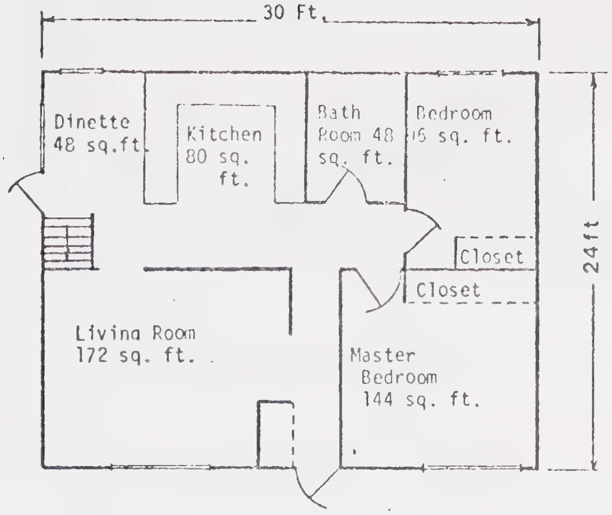


Fig. 2.1 Basic Floor Plan of 720 Square Feet

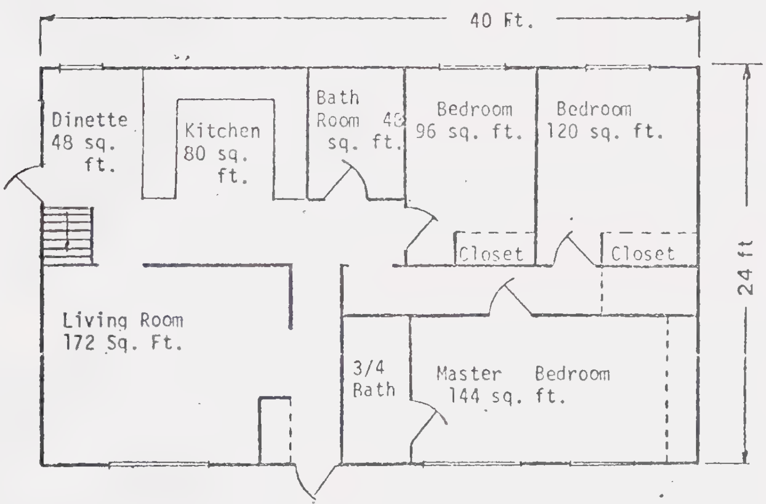


Fig. 2.2 960 square feet (40' x 24') three bedroom floor plan (expansion one).

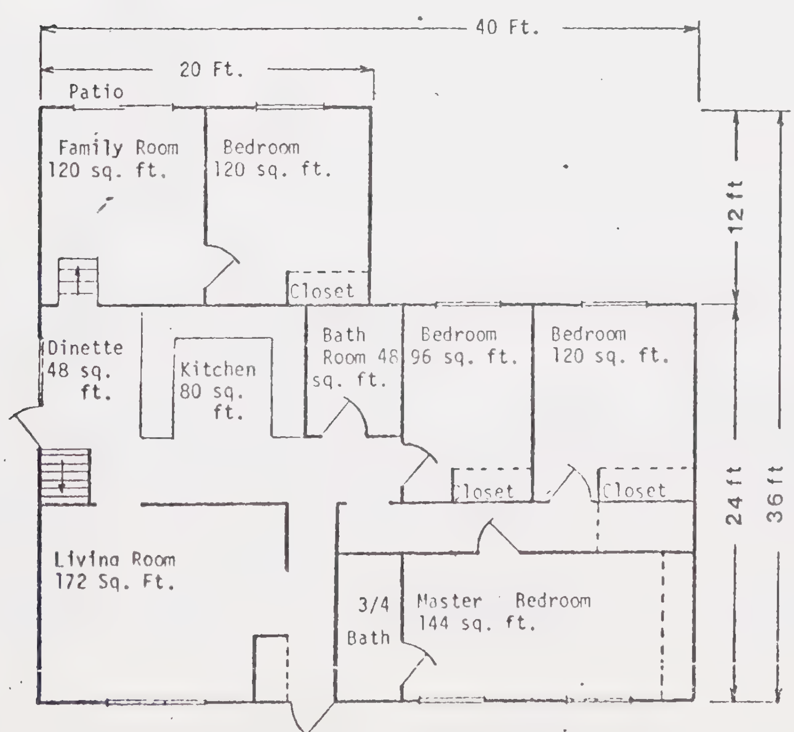


Fig. 2.3 1200 square feet four bedroom floor plan including a family room (expansion two).

CHAPTER III

DEVELOPING A PANEL SYSTEM FOR THE FLEXI-GROW HOUSING SYSTEM

At present, home construction is predominantly on-site and involves many small builders.

To reduce the total cost of a home, materials which are less costly than presently used are desirable and new techniques to produce dwelling components need to be developed.

3.1 The Mobile Home Market

In the present market, the lowest price dwellings available are mobile homes.

Production of mobile homes in the United States in 1968 reached 280,000 units at an average cost of $8.30/sq. ft. as compared to $13.0/sq. ft. for conventional housing excluding land (approximately $3.00/sq. ft. of this difference can be accounted for by a basement). The average mobile home unit has a kitchen, living room, dinette, one or two baths, three bedrooms, with a total living space of six hundred and eighty square feet. [4]

The mobile home industry is also capitalizing on the use of plastics to reduce the total cost of a dwelling. In 1971 approximately two hundred and forty pounds of plastics went into each of an estimated four hundred and eighty five thousand completed homes, placing the mobile home industry in first place for plastics consumption in the single-family housing market. Total consumption was posted at about fifty five thousand tons (one hundred twenty

million pounds).

In 1970, mobile homes accounted for 45% of all single-family dwellings, for 72% of the homes selling for less than twenty thousand dollars, and for 95% of the homes selling for less than fifteen thousand dollars.

The retail prices for mobile homes in the United States in 1970 average six thousand one hundred and ten dollars, or about \$8.35/sq. ft., completely furnished. On the other hand, a site-built, single-family home costs an average of \$16.0/sq. ft. and is unfurnished. In 1970, the median price of a site-built single-family home was twenty six thousand and two hundred dollars including land.

The mobile home industry pioneered in industrialized building and has been instrumental in introducing a number of plastic components into the mobile home industry.

The key would appear to be industrialization, whereby the work is performed in a factory using relatively low cost labor under controlled, often automated conditions replacing on-site high rate labor trades. [5][6][7]

There are some disadvantages to mobile homes. One problem is finding a place to locate them. They are not welcome additions to the housing scene in many urban and suburban areas. Many Canadians wouldn't want their neighbors to live in a mobile home [8].

3.2 Structural Sandwich Panels

Sandwich panels have received much attention as building components [4][5][6] in recent years. Sandwich panels as building components have advantages in terms of total cost reduction through:

1. Mass production;
2. Less material handling;
3. Mass-buying of raw-materials; and
4. Lower rate labor.

Two fundamental approaches with respect to the erection of the FLEXI-GROW housing system can be used from a factory production standpoint.

1. Build the entire home in sections (large modules) and assemble these sections on-site.
2. Produce panels as components in the factory that can be readily assembled on location.

Sandwich panels as components satisfy the requirement of the FLEXI-GROW housing system particularly with respect to the following points:

1. Interchangeability of components;
2. Flexibility in expansion;
3. High quality; and
4. Satisfactory durability.

Therefore sandwich panels produced as components in the factory and readily assembled on location have been selected as the production method.

3.3 Load Bearing Panels Versus Non-Load Bearing Panels

The simplest type of sandwich panel is a three-layered laminated structure consisting of a thick, low density core which is bounded by a facing layer on either side. Each facing layer is a thin, stiff, strong sheet of high density material. Based on equal overall weights of material used, the sandwich panel is a much stronger structure, with respect to bending, than a homogeneous plate constructed from the same facing material.

The panel core has several vital functions. It should be stiff enough in the direction perpendicular to the faces to ensure that they remain a fixed distance apart. It should be stiff enough in shear to ensure that when the panel is bent the faces do not slide over each other. If this last condition is not fulfilled the faces merely behave as two independent beams or panels and the sandwich effect is lost. The core should also be stiff enough to keep the faces nearly flat. Otherwise it is possible for a face to buckle locally (wrinkle) under the influence of compressive stress in its own plane.

The core should satisfy all these requirements. It is also important that the adhesive used does not permit substantial relative movements of the faces and the core.

From the viewpoint of the design of the FLEXI-GROW housing system a load bearing panel has advantages when compared with a non-load bearing panel in terms of total cost reduction:

1. Less erection time is required;
2. No extra cost is necessary to set up the frame of the dwelling; and
3. The panel system makes it easy to change and expand the floor plan.

The decision was, therefore made to design the system using load bearing panels.

3.4 The Panel Core

The core of building panels are made from such materials as perforated chipboard, balsa wood, several kinds of expanded plastics and foamed glass. Research [10] has shown that one of the most desirable materials, as the core of a load bearing building panel, is honeycomb kraft paper impregnated with resin.

Urethane foam is used to improve the thermal conductivity of the panel to meet the requirements of the Canadian Code for Residential Construction [11].

A typical cross section of the panel is illustrated in Figure 3.1.

Resin treatment of paper is one of the first problems to be considered in paper core manufacturing. Since panels are likely to be subjected to damp or wet conditions, the presence of resin in the paper is necessary to yield a product that is permanently strong and stiff under wet conditions. Resin-impregnated papers [10] have been shown to retain 75 percent of their dry strength after water soaking. Water soaking causes untreated paper to lose

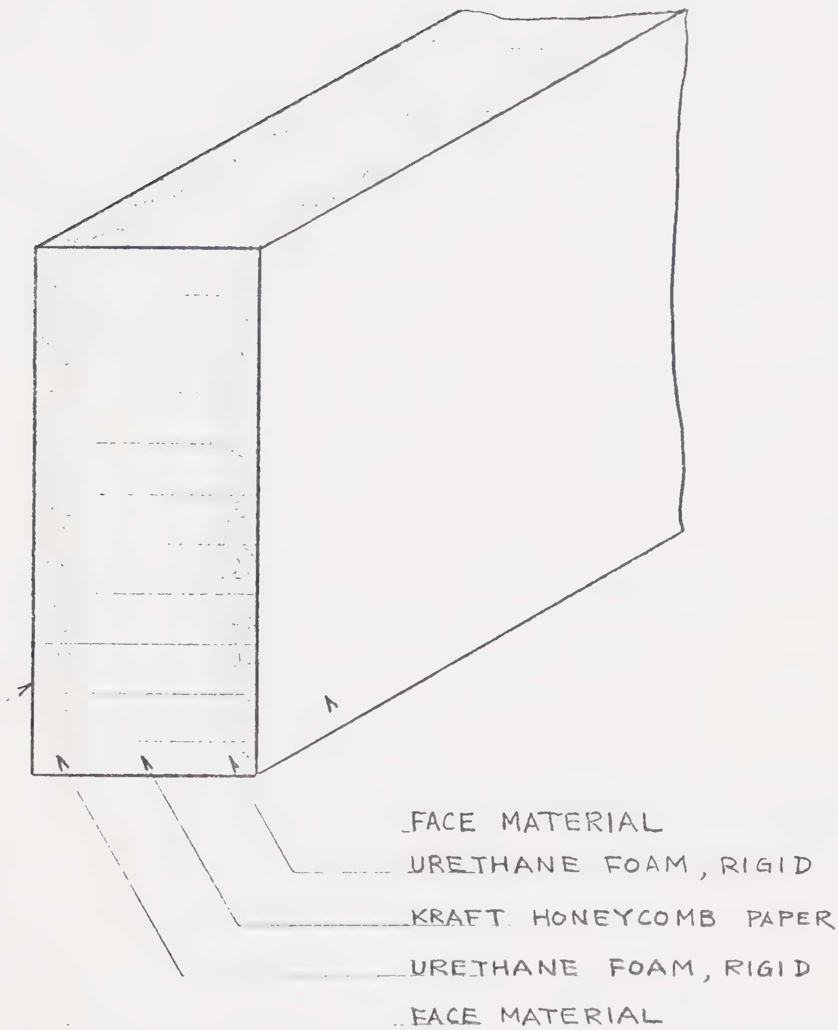


FIGURE 3.1 A TYPICAL CROSS-SECTION OF THE PANEL

almost all its strength.

Research [10] has found that a resin treatment with 15 percent water-soluble resin was found to be adequate for providing paper of good strength when wet, decay resistance, and handling characteristics during corrugation and subsequent fabrication. A resin content in excess of 15 percent does not seem to produce a gain in strength commensurate with the increased quantity of resin used. In one series of tests, paper containing as little as 5 percent water-soluble resin was satisfactory in strength but showed less resistance to decay organisms than paper with a 15 percent resin.

3.5 Outer Face Material of the Panel

Almost any structural material which is available in the form of a thin sheet may be used to form the faces of a sandwich panel. In the building industry the choice of face materials is wide, including plywood, hardboard, plaster, plastics, asbestos cement and a great number of composite materials.

The basic requirements of the outer and inner face materials are:

1. To be suitable for a continuous production process in order to obtain high production efficiency and reduce the panel manufacturing cost;
2. To obtain less material handling;
3. To provide a going system, which will give sufficient stiffness and strength to the panels;
4. To eliminate visible lines at the joints; and
5. To obtain joints, which may easily be manufactured.

It is, therefore, desirable to have the face materials supplied in coils.

The criteria used as a basis in selection of the outer face material are as follows:

1. Cost ($/sq. ft.);
2. Weight (lbs/sq. ft.);
3. Weatherability;
4. Durability;
5. Applicability to the production line (rolled material is preferred);
6. Availability of glue;
7. Workability;
8. Impact resistance;
9. Paintability;
10. Water absorption;
11. Appearance;
12. Cleanability;
13. Thermal expansion (100° F temperature difference may exist between the inside and the outside of the dwelling).

The determination of the optimal face thickness from a theoretical viewpoint is discussed in [15].

When the bending strength is specified,

$$t = \frac{\mu c d}{2\mu_f}$$

where t = the optimum face thickness

μ_c = the density of the core material, honeycomb paper core, 0.00071 lbs/in^3.

μ_f = the density of the face material,

steel = 0.2829 lbs/in^3.

d = the panel thickness

(three inches when the thickness of face material is very thin).

$$t = \frac{0.00071 \times 3}{2 \times 0.2829} = 0.0037 \text{ in.}$$

Also, if it is known or suspected that failure of the face will occur as a result of local instability (e.g. by buckling into the cells of honeycomb of fixed cell dimensions), then,

$$t = \frac{3\mu_c d}{2\mu_f}$$

$$= \frac{3 \times 0.00071 \times 3}{2 \times 0.2829}$$

$$= 0.01129 \text{ in.}$$

This thickness is approximately equivalent to a thirty gauge steel sheet.

The determination of the optimal face thickness from a practical viewpoint is interrelated to:

1. The modulus of elasticity of the face material;
2. Combined weight of the faces and the core;
3. The bending moment which the beam must carry at failure;
4. The ultimate strength of the face material or the wrinkling stress (whichever is the lower);

5. The impact resistance of the face material; and
6. Thermal expansion of the face material.

Some experimental analysis would be desirable to solve the optimal face thickness based on the designed load bearing structural panels. (This analysis was not done as part of this study).

The outer face materials which were considered are as follows:

1. Aluminum

   ALCOA 2024-T3 ALCLAD sheet SPEC. QQ-A-362 COND. T gauge 22 (0.025 in. thick)*;
2. Steel Sheet

   STELCO STELCOLOUR prefinished sheet steel or equivalent gauge 22 (0.0299 in. thick) "Wallclad" manufactured by Wallclad Products Ltd. uses 20 gauge precoat steel face and a U. S. firm producing similar panels uses a 22 gauge steel face;
3. Plywood

   1/4 in. thick available from MacMillan Bloedel Building Materials;
4. PVC 9polyvinyl chloride);
5. Asbestos cement; and
6. Medium density hardboard.

One-quarter inch plywood, asbestos cement, and medium density hardboard are not available in coils. PVC doesn't have suitable properties to support the load. Therefore these materials

---

* See [13]

have been eliminated as the outer face material.

Aluminum is not recommended for use as the facing material because it is anodic to most heavy metals and electro-chemical corrosion from bimetallic contacts may occur. This direct contact of aluminum with more noble metals such as copper and copper-rich alloys, and to a lesser extent lead, iron and steel can be a source of corrosion trouble [14].

Table 3.1 gives a summary of steel, aluminum and plywood based on the design criteria selected.

Table 3.1 A Summary of the Typical Outer Face Materials

Criteria	Aluminum 0.025 in.*	Steel Sheet 0.0299 in.	Plywood 1/4 in.*
1. Cost $/sq.ft.	0.483	0.255	0.20
2. Weight lbs/sq.ft.	0.574	1.5	0.79
3. Weatherability	*strong	Paint coating is required	acceptable if painted
4. Durability	adequate	adequate	adequate
5. Applicability to the production line	OK	OK	no coiled material availabl
6. Availability of glue	3M EC1828	3M EC1828	3M EC1828
7. Workability	Excellent	Good	Excellent
8. Impact resistance	adequate	adequate	adequate
9. Paintability	Excellent	Excellent	Excellent
10.Water absorption	Excellent	Excellent	*Good
11.Appearance	Acceptable	Acceptable	Acceptable
12.Cleanability	Easily cleaned	Easily cleaned	Reasonably easy to clean
13.Thermal expansion	0.091 in.	0.179 in.	___

* See [13]

The chosen outer face material is prefinished steel sheet, 22 gauge (0.0299 in.) based on the design criteria.

Prepainted steel was selected initially because:

1. No initial capital investment is required for surface finishing; and
2. A wide range of colors is available with prepainted materials.

3.6 Inner Face Material of the Panel

The criteria required for the inner skin will be as follows:

1. Appearance;
2. Cost $/sq. ft.;
3. Flexibility to re-decorate;
4. Weight lbs/sq. ft.;
5. Impact resistance;
6. Dent proof;
7. Sound proof;
8. Durability;
9. Applicability to production line;
10. Workability; and
11. Cleanability.

Any thin sheet form may be used as an inner face material. The selection of the materials and the determination of the thickness of the material are the same as 3.5.

Although, the outer face and the inner face may be different materials, the panel as a whole should be in balance with respect

to strength and panel stiffness [16]. For these reasons and the ability to meet the design criteria 22 gauge steel sheeting was selected as the inner face material (Note table 3.2).

Table 3.2 A Summary of the Effectiveness of the Inner Face Material According to the Selected Design Criteria

Material Criteria	Steel Sheet, 22 gauge (0.0299 in.)
1. Appearance	acceptable
2. Cost $/sq. ft.	0.255
3. Flexibility to re-decorate	excellent
4. Weight lbs/sq. ft.	1.5
5. Impact resistance	strong enough
6. Dent proof	excellent
7. Sound proof	good
8. Durability	excellent
9. Applicability to production line	OK
10. Workability	good
11. Cleanability	excellent

3.7 Wall Connection Method

In order to build dwellings using prefabricated panels, the wall connection method requires thorough study. The connection method affects the erection time, the ease of expansion of the dwelling, the cost of the panels, the initial investment of the plant facility and the appearance of the total wall and dwelling.

The floor plan is designed so that the vertical line which appears at the connection of the panels is usually hidden by an inside wall connection or in a closet.

3.7.1 Connection of the Panels

The following connections were developed providing connection blocks:

(1) Corner connection

(2) "T" connection

(3) Straight connection

The exterior wall panel will be fastened by anchor bolts on the bottom (see Figure 3.3) and also secured firmly to the trusses using brackets.

The interior wall panel will be fixed to the subfloor by fastening and the top portion of the panel will also be fastened to the trusses.

The connection schedule is shown in Figure 3.2.

Corner Connection

This is the connection method to join two exterior wall panels or two interior wall panels at ninety degrees at a corner.

The detail of the corner connection method is shown in Figure 3.3.

"T" Connection

Figure 3.4 illustrates the detail of the "T" connection to connect either exterior wall panels or interior wall panels.

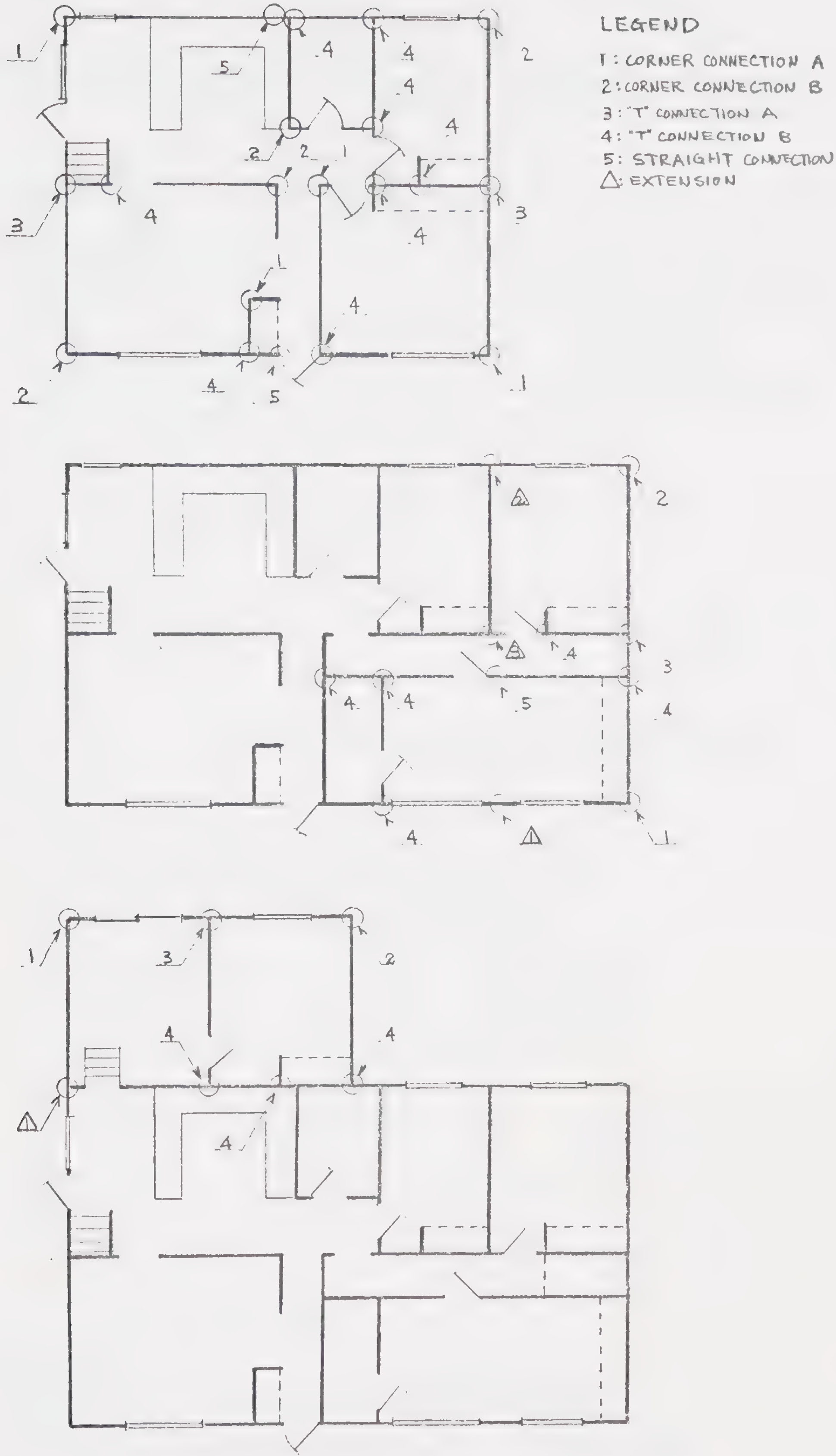
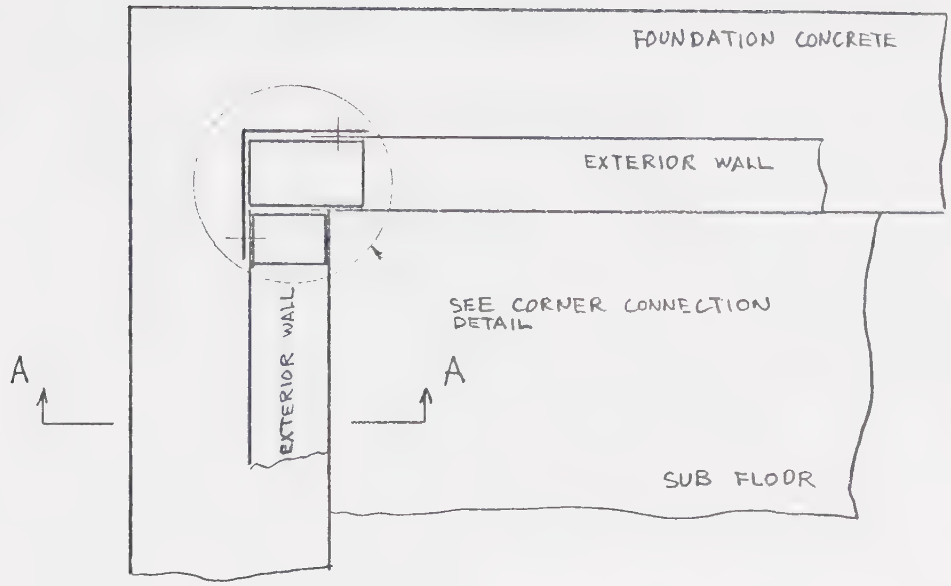
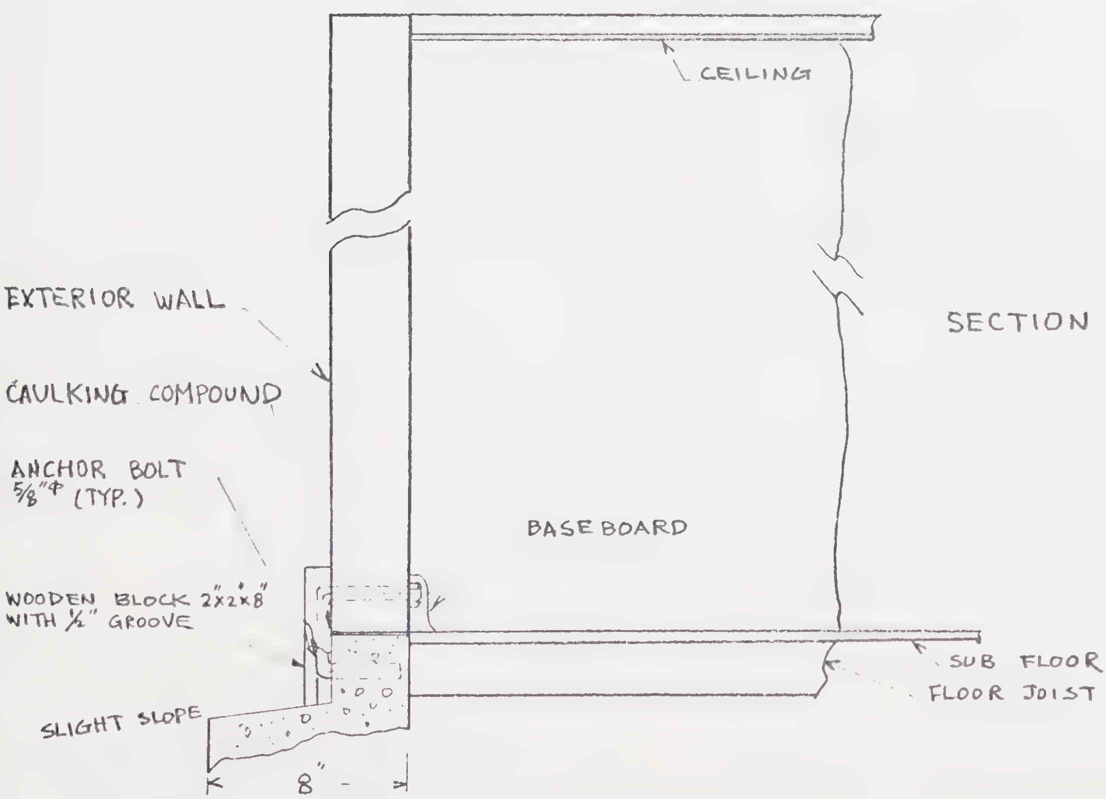


FIGURE 3.2 CONNECTION SCHEDULE FOR THE DWELLING



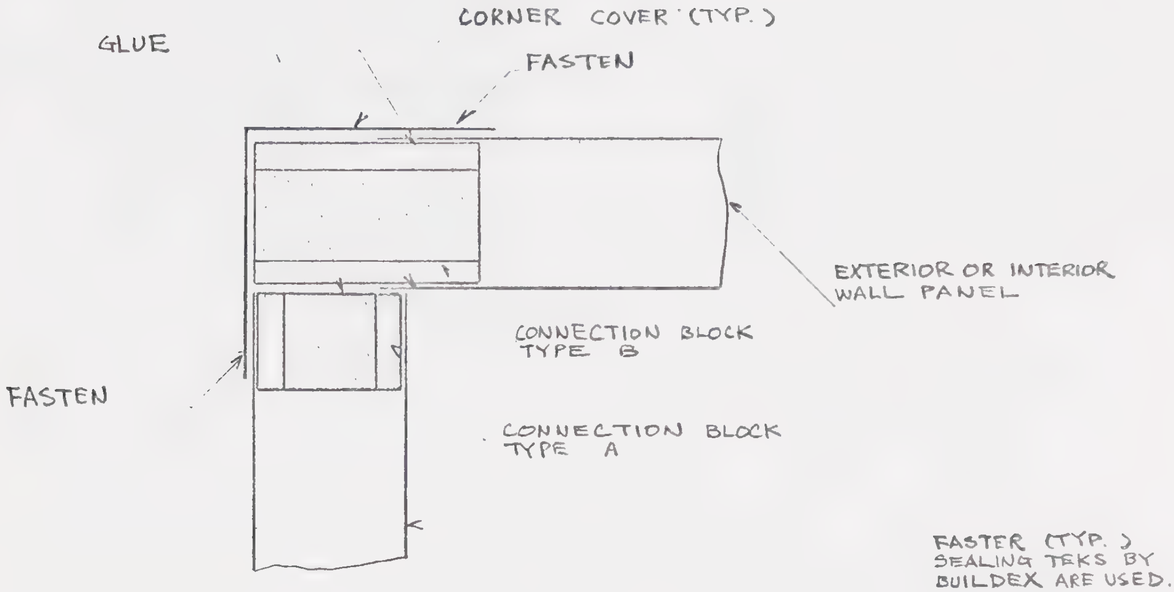
CORNER CONNECTION (PLAN VIEW)



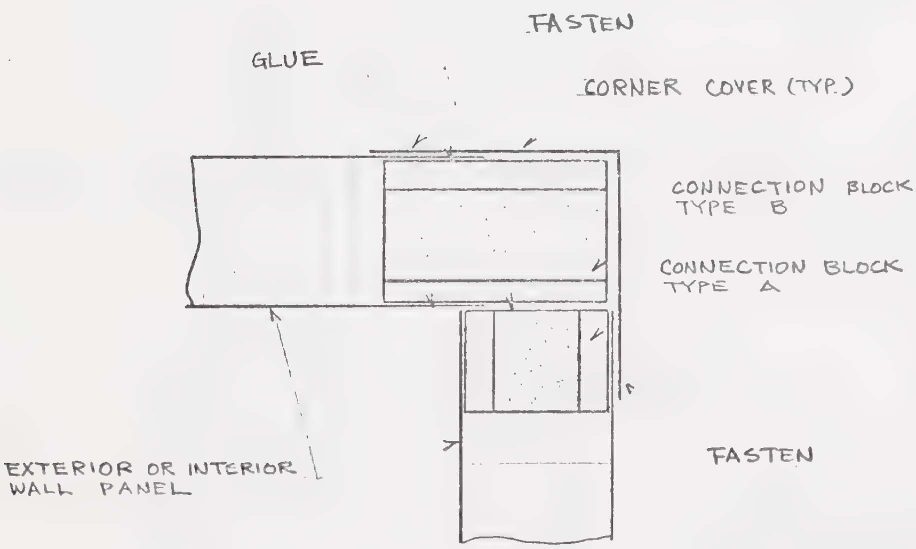
SECTION A-A

FIGURE 3.3 THE CORNER CONNECTION

Corner connection detail



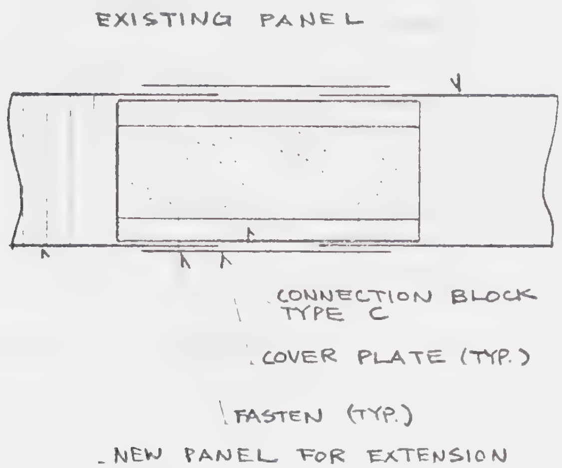
CORNER CONNECTION A



CORNER CONNECTION B

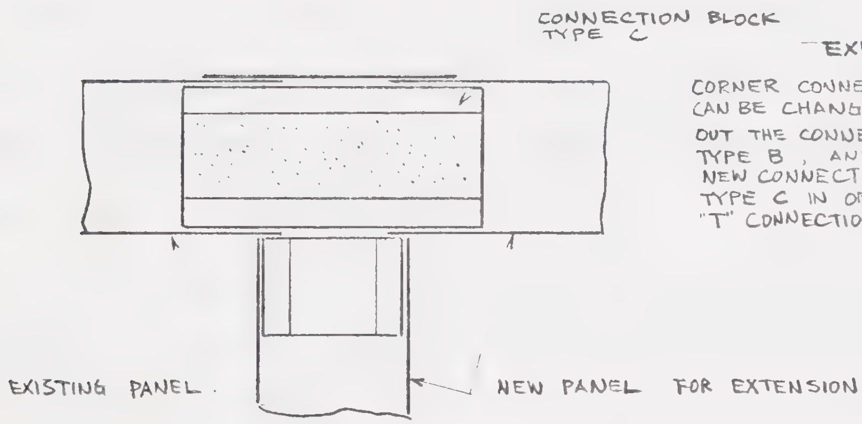
Figure 3.3 continued

CORNER CONNECTION EXTENSION DETAIL



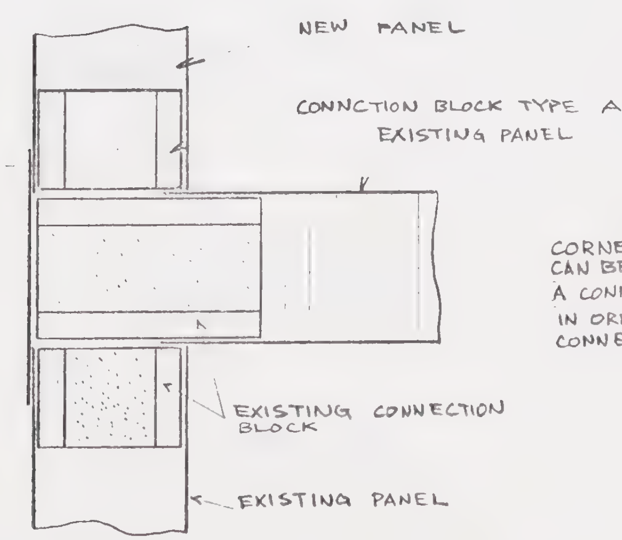
EXPANSION ONE

CORNER CONNECTION A CAN BE CHANGED BY TAKING OUT THE CONNECTION BLOCK TYPE A & B, AND INSERT NEW CONNECTION BLOCK TYPE C IN ORDER TO MAKE A STRAIGHT CONNECTION



EXPANSION ONE

CORNER CONNECTION B CAN BE CHANGED BY TAKING OUT THE CONNECTION BLOCK TYPE B, AND INSERT NEW CONNECTION BLOCK TYPE C IN ORDER TO MAKE "T" CONNECTION



EXPANSION TWO

CORNER CONNECTION A CAN BE CHANGED BY PUTTING A CONNECTION BLOCK TYPE A IN ORDER TO MAKE "T" CONNECTION

FIGURE 3.3 CONTINUED

Straight Connection

This connection method is used to join two exterior wall panels or two interior wall panels as shown in Figure 3.4.

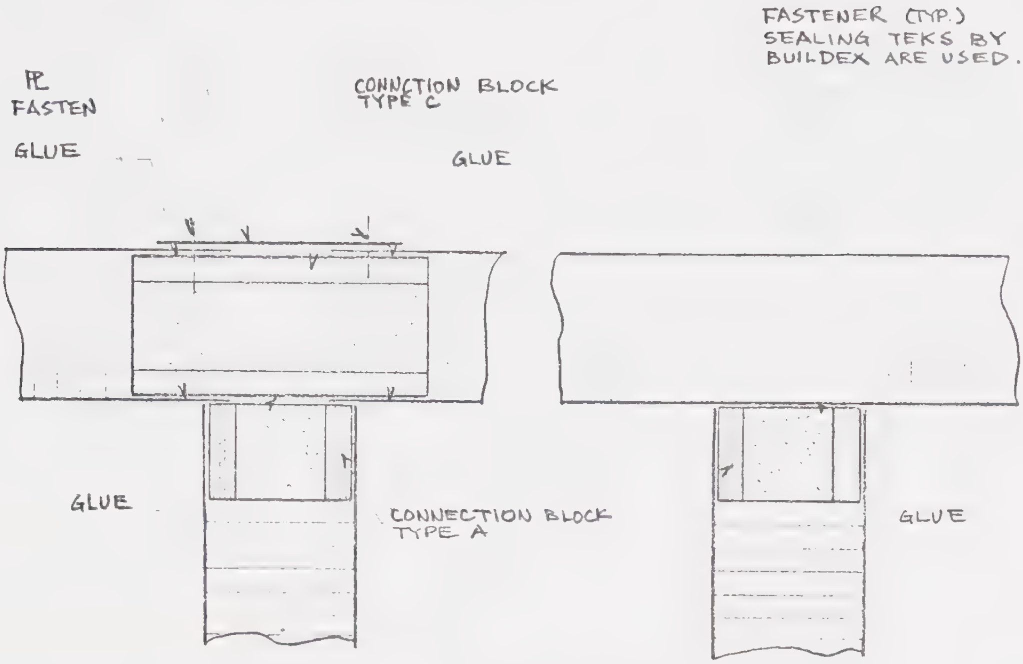
3.7.2 Panel Connection to the Roof System

The roof structure of the dwelling will be built using the trusses which are prefabricated and readily available in the market. A typical truss to suit the dwelling is shown in Figure 3.5. The estimated material and installation cost comparison of the roof structure as well as the roof and the floor is given in Table 3.3. The total cost to achieve the roof structure and the roof of the dwelling will be less expensive when the conventional method is used rather than using the panels designed for this dwelling.

The trusses and the triangular side wall panels will be placed on the exterior and interior wall panels and fastened by the brackets provided.

The connection method for these panels and the brackets are shown in Figure 3.5.

"T" CONNECTION



"T" CONNECTION A

"T" CONNECTION B

STRAIGHT CONNECTION

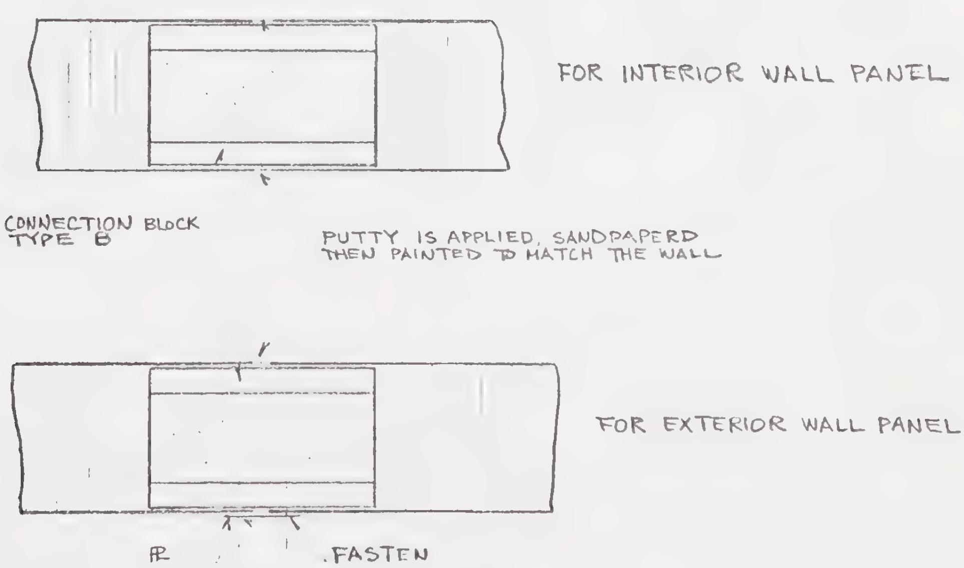
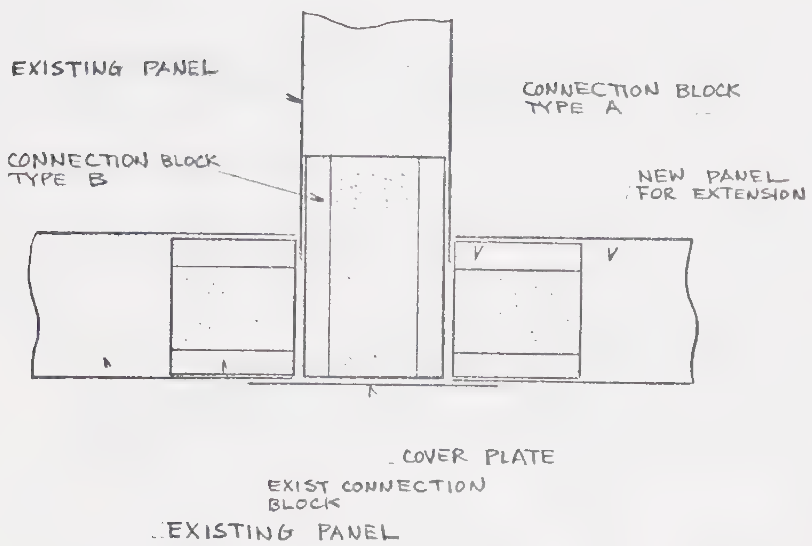


FIGURE 3.4 "T" CONNECTION, STRAIGHT CONNECTION AND CONNECTION BLOCK

"T" connection Extension Detail



EXPANSION ONE

"T" CONNECTION A CAN BE CHANGED BY TAKING OUT THE CONNECTION BLOCK C AND INSERT CONNECTION BLOCK TYPE B & A IN ORDER TO MAKE A "T" CONNECTION

Connection Block , length 7'-10"(typ.)

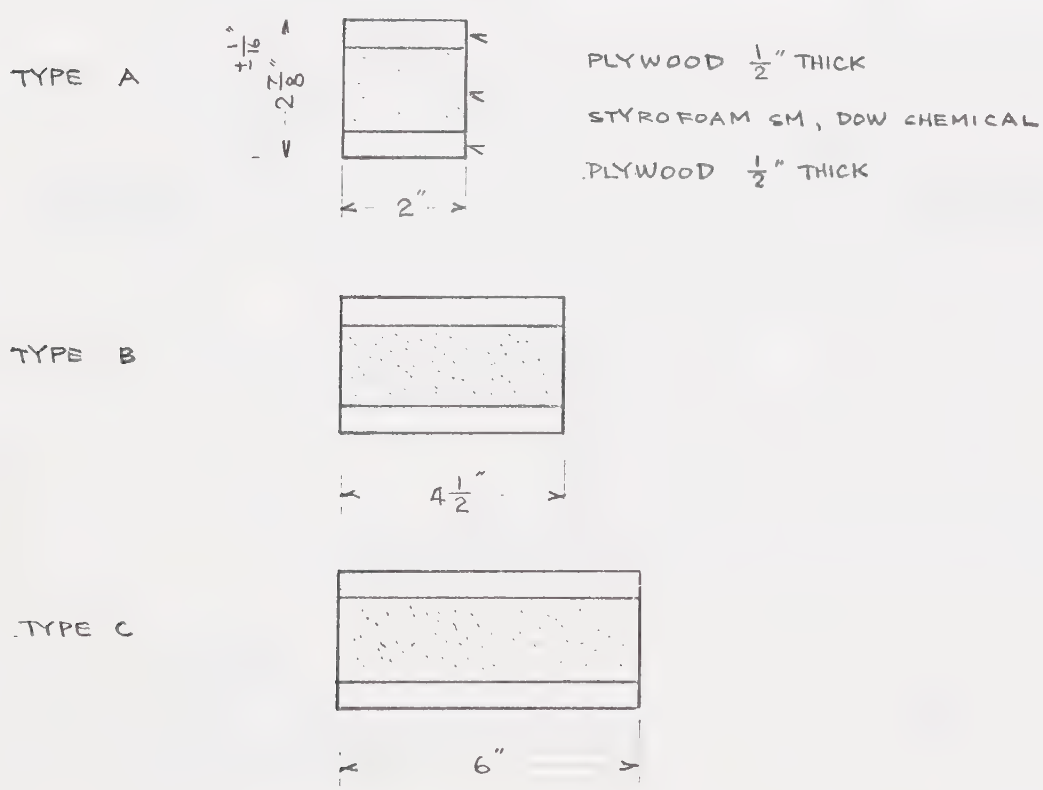


Figure 3.4 continued

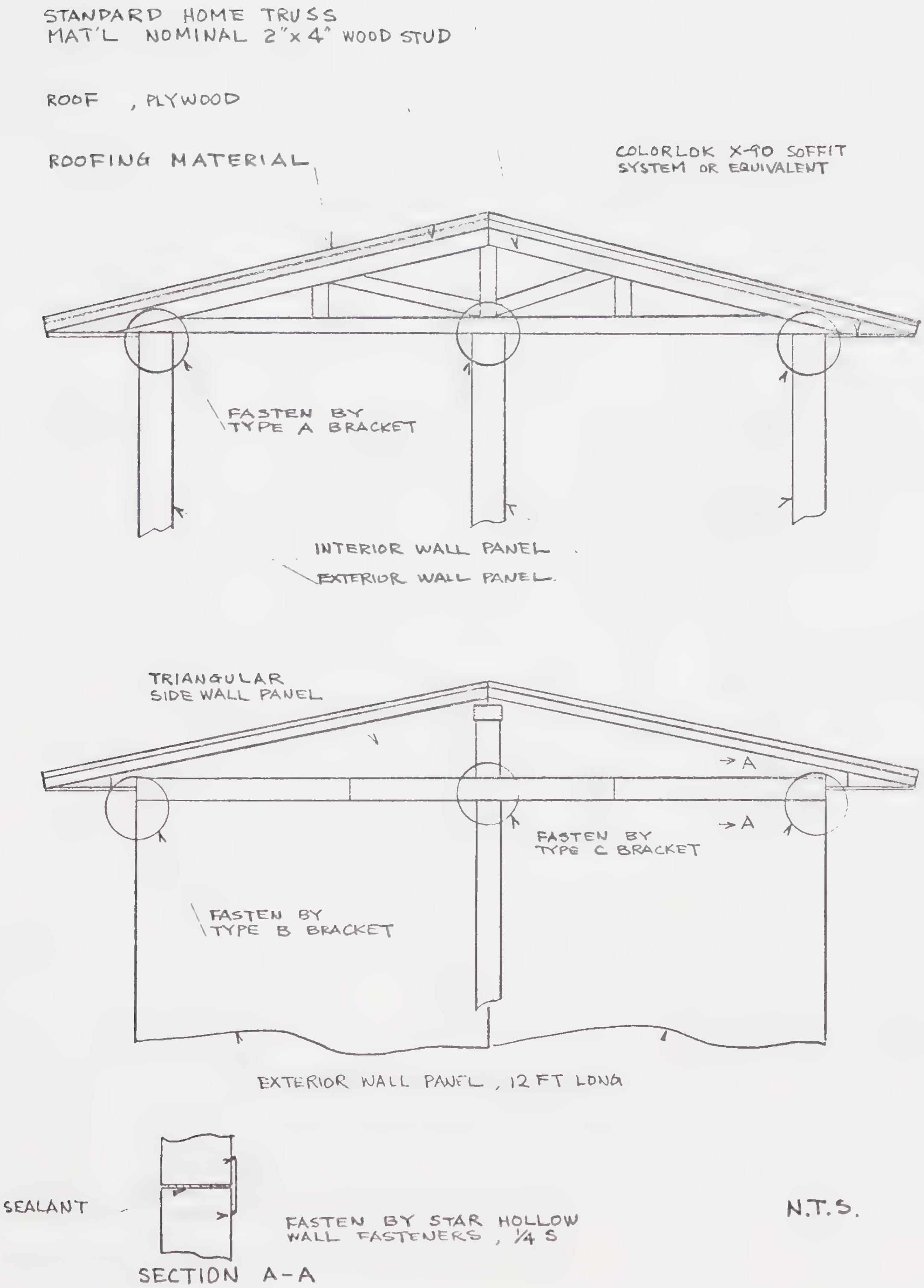
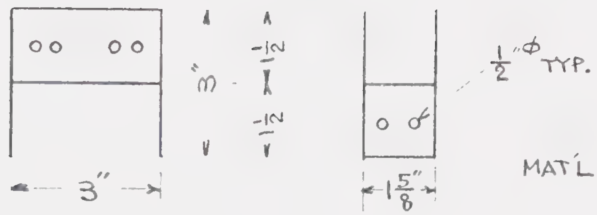


FIGURE 3.5 THE BRACKETS TO FASTEN THE ROOF SYSTEM

TYPE A



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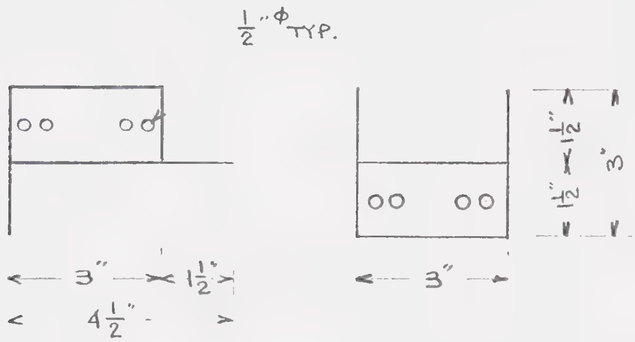
TYPE B



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TYPE C

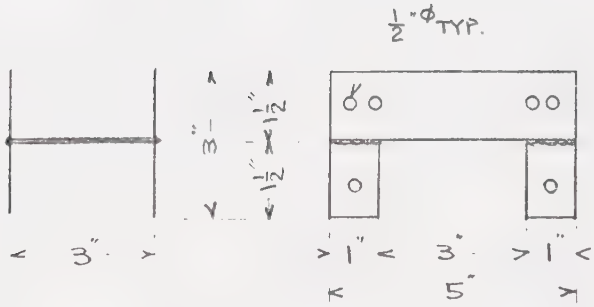

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FIGURE 3.5 CONTINUED

Table 3.3. The Estimated Material and Installation Cost Comparison of Roof, Roof Structure and Floor

	MAKE		BUY	
	Sandwich Panel 3" thick kraft honeycomb paper, $1.93/sq.ft.		Materials available in the market FOB Edmonton	
ROOF				
1. Material cost	Panel $1.93/sq.ft. x (14'-6" x 34') x 2	$1,903	Fir Plywood Sheathing 4'x8' x 3/8 " $0.3/sq.ft. x (4'x8') x 36 reg'd	$346
	Roofing materials $17/100 sq.ft. x (34'x26')=	$ 151	Roofing material $17/100 sq.ft. x (34'x26') =	$151
			Fiberglas A.F. home insulation 2-1/2 " thick, above the ceiling $8.45/100 sq.ft. x 720 sq.ft. =	$ 61
	Total material cost =	$2,054	Total material cost =	$558
2. Installation cost	$4.50/hr x 40 M.H./2000 lbs. x 3 lbs/sq.ft. x (14'-6" x 34') x 2 =	$ 268	Sheathing $4.50/hr x 4 hrs. =	$ 18
			Roofing $8/100 sq.ft. x (14'-6"x34') x 2 =	$ 79
	Total installation cost =	$ 268	Total installation cost =	$ 97

Table 3.3. (continued)

	MAKE		BUY	
ROOF				
3. Overhead 50% of installation cost	0.5 x $268 =	$134	0.5 x $97 =	$ 49
Total roof cost per home	$2,054 + $268 + $134 =	$2,456	$558 + $97 + $49 =	$704
ROOF STRUCTURE				
1. Material cost	$1.93/sq.ft. x (12'-3" x 1/2) x 28 req'd =	$662	Truss 24 ft. span 2 ft. high @ $21.50 x 14 req'd =	$301
2. Installation cost	$4.50/hr x 40 M.H./2000 lbs. x 3 lbs./sq/ft. x (12'-3" x 2' x 1/2) x 28 req'd =	$ 93	$4.50/hr x @ 1/4 M.H. x 14 req'd =	$ 16
3. Overhead 50% of installation cost	0.5 x $93 =	$ 47	0.5 x $16 =	$ 8
Total roof structure cost per home	$662 + $93 + $47 =	$802	$301 + $16 + $8 =	$325

Table 3.3. (continued)

	MAKE		BUY	
FLOOR				
1. Material cost	\$1.93/sq.ft. x 720 sq.ft.=	\$1,390	Subfloor Fir plywood 4'x8'x5/8" \$0.5/sq.ft. x (4'x8') x 24 req'd =	\$384
2. Installation cost	\$4.50/hr x 40 M.H./2000 lbs. x 3 lbs/sq.ft. x 720 sq.ft. =	\$ 195	\$7.50/hr. x 42 M.H./MFBM x (4'x8'x5/8") x 24 req'd =	\$151
3. Overhead 50% of installation cost	0.5 x \$195 =	\$ 98	0.5 x \$151 =	\$ 76
Total floor cost per home	\$1,390 + \$195 + \$98 =	\$1,683	\$384 + \$151 + \$76 =	\$611

3.8 The Panel Design Calculations

The chosen panels are load bearing. The panels are designed to satisfy the floor plan requirements outlined in section 2.3. The following materials are used as components of the panels designed.

1. Urethane foam
2. Kraft honeycomb paper
3. Steel sheet, 22 gauge

3.8.1 Determination of the Core Thickness of Interior and Exterior Wall Panels

Based on the design load of 873 lbs./ft. (see Appendix G for the details) the core thickness of the interior and the exterior wall panels is calculated [15].

The equations to be used are applicable based on the following assumptions:

(1) Panel is considered as a column, both ends free;

(2) Load is uniformly distributed;

(3) Load is vertically applied;

(4) The skins of the sandwich panel are separated by an equal distance and firmly bonded to the core; and

(5) The material of the skins of the sandwich panel is much stiffer than the core material.

It is necessary to make sure that the chosen thickness of the facing material (t), 22 gauge steel, is adequate to support the axial load p, 873 lbs/ft., without wrinkling. The wrinkling stress is calculated by the following equation.

$$\sigma = B_1 E_f^{1/3} E_c^{2/3}$$

where σ = wrinkling stress

3.8 The Panel Design Calculations (continued)

B_1 = constant factor, in this case 0.5*

E_f = the modulus of elasticity of the facing material, 3×10^7 p.s.i.

E_c = the modulus of elasticity of the core material 11,900 p.s.i. **

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* See page 238 of [15]

** This is obtained from Union Camp's technical information.

$$\sigma = 0.5\ (3 \times 10^7)^{1/3}(11{,}900)^{2/3}$$
$$= 0.5 \times 30^{1/3} \times 10^2 \times 11.9^{2/3} \times 10^2$$
$$= 80{,}968 > 60{,}000 \text{ p.s.i.}^{***}$$

This factor is large enough to prevent wrinkling.

The necessary thickness of the core can be determined by the following equation[15].

$$c \geq \frac{p}{2bG}\ \left[1 + \sqrt{\left(1 + \frac{8}{\pi^2} \times \frac{L^2 b}{t} \times \frac{G^2}{E_f p}\right)}\ \right]$$

where

c = Thickness of core (in)

p = The axial load (lbs)

b = Width of panel (in)

G = The modulus of rigidity of the core (psi)

L = Height of panel (in)

t = Thickness of the facing material (in)

E_f = The modulus of elasticity of the facing material (psi)

Given:

p = 873 lbs.

b = 12 in.

G = 2,800 psi*

L = 96 in. (interior panel height)

t = 0.0299 in** (22 gauge steel)

E_f = 3×10^7 psi***

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* See page 251 of [15]
** See page 451 of [19]
*** See page 430 of [19]

$$c \geq \frac{873}{2 \times 12 \times 2800} \left[1 + \sqrt{\left(1 + \frac{8}{3.14^2} \times \frac{96^2 \times 12}{0.0299} \times \frac{8800^2}{3\text{x}10^7\text{x}873}\right)}\,\right]$$

$$= 0.012991\ [1 + \sqrt{1 + 8873.87}\ ]$$

$$= 0.012991\ [1 + \sqrt{8874.871}\ ]$$

$$= 0.012991\ (1 + 94.206)$$

$$= \underline{\underline{1.236 \text{ in.}}}$$

The thermal conductivity of the panel is another critical factor to be considered. The formula for the coefficient of transmission of a compound wall of several materials having individual thicknesses in inches of x_1, x_2, x_3, etc. and conductivities of k_1, k_2, k_3, etc. is given as follows [20].

The assumptions are:

(1) Each material is homogeneous; and

(2) Air spaces are considered to be "dead" air spaces.

$$U = \frac{1}{\frac{1}{f_i} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \frac{1}{f_o}} = \frac{1}{R}$$

where f_i = inside surface coefficient for still air = 1.46

f_o = outside surface coefficient

R = thermal resistance

Based on the typical cross section of the panel described in Figure 3.1, several combinations of erethane and air space were tried to arrive at an acceptable panel thickness which satisfies the Building Code.

The thickness of urethane and air space arrived at are as follows:

1. Urethane foam, rigid 0.6 in.
2. Air space, foam sandwiched by urethane 1.8 in.
3. Urethane foam, rigid 0.6 in.

The total panel thickness, therefore, is three inches.

The value of this combination of material will be:

$$U = \frac{1}{\frac{1}{1.46} + \frac{0.05}{118} + \frac{0.6}{0.15} + \frac{1}{1.03} + \frac{0.6}{0.15} + \frac{0.05}{118} + \frac{1}{1.46}}$$

$$= \frac{1}{0.68 + 0.0004 + 4 + 0.97 + 4 + 0.0004 + 0.68}$$

$$= \frac{1}{10.33} = \frac{1}{R}$$

Hence, $R = 10.33 > 10^{*}$. This R value is large enough to satisfy the Building Code.

From the viewpoint of the strength required of the panel, 1.236 inches of panel thickness are sufficient. However, the thermal conductivity, which the panel should have, requires a three inch thickness to satisfy the requirements of the Building Code. Therefore, the final thickness of the panel is determined as three inches.

---

* Canadian Code for Residential Construction 1970, page at 82.

CHAPTER IV

SERVICE FACILITIES OF THE SYSTEM

The service facilities studied for the dwelling were considered and selected on the basis of the criteria below:

(1) Economically optimal with respect to the final cost;

(2) Applicability to the FLEXI-GROW housing system;

(3) Satisfactory performance of the system; and

(4) Acceptable by the home owner.

The service facilities discussed here are plumbing, heating and ventilation, and electrical wiring.

4.1 Plumbing

Home extensions require no extension of the plumbing system. The required plumbing for the 3/4 bathroom in the first extension is included in the initial plumbing.

The kitchen and bathroom use a common plumbing wall (see floor plan, Figure 2.1) because:

1. The plumbing wall is ready to install in the required place;
2. The pipes are pre-assembled, pressure-tested and inspected in the manufacturing plant; and
3. The plumbing wall provides the necessary outlets for the bathtub, washbasin, kitchen sink, etc., ready to install.

The wall to separate the kitchen and the bathroom (see Figure 4.1) is a sandwich panel construction utilizing a urethane

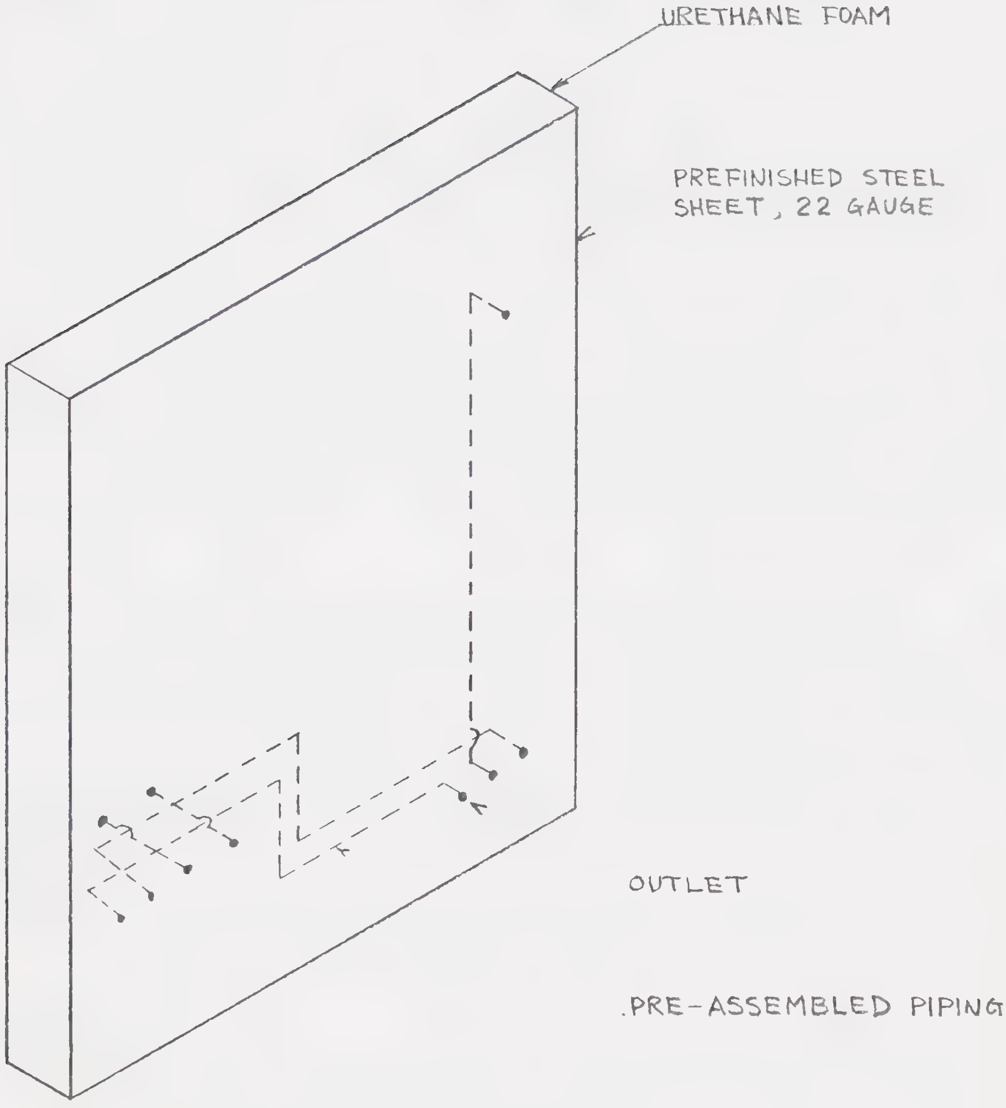


FIGURE 4.1 PLUMBING WALL

foam core with 22 gauge prefinished steel sheet. Honeycomb kraft paper is not used in this core for ease of piping installation. The completion of the bathroom is illustrated in Figure 4.2.

4.2 Heating and Ventilation

The system chosen for heating and ventilating is a "warm air" system, which is the standard system in most homes, with a centrally located source of supply. The air ducts are located directly below the floor. The subfloor is designed with a knock out panel to accommodate floor diffusers. When the home is expanded, the air ducting will be extended to the new area and connected to the floor diffusers.

The mechanical system as well as being adaptable to the FLEXI-GROW housing system is very versatile. Cooling, humidification and air cleaning or any combination of the three, can be incorporated in the basic heating system as options with no major physical alterations.

The general design and layout are shown in Figure 4.3.

4.3 Electrical Wiring

Most conventional residential homes have electrical wiring located inside the walls, In the FLEXI-GROW housing system, the walls are not equipped with any conduit pipes for cables due to the continuous panel production method used.

A typical electrical wiring for the dwelling is developed and shown in Figure 4.4.

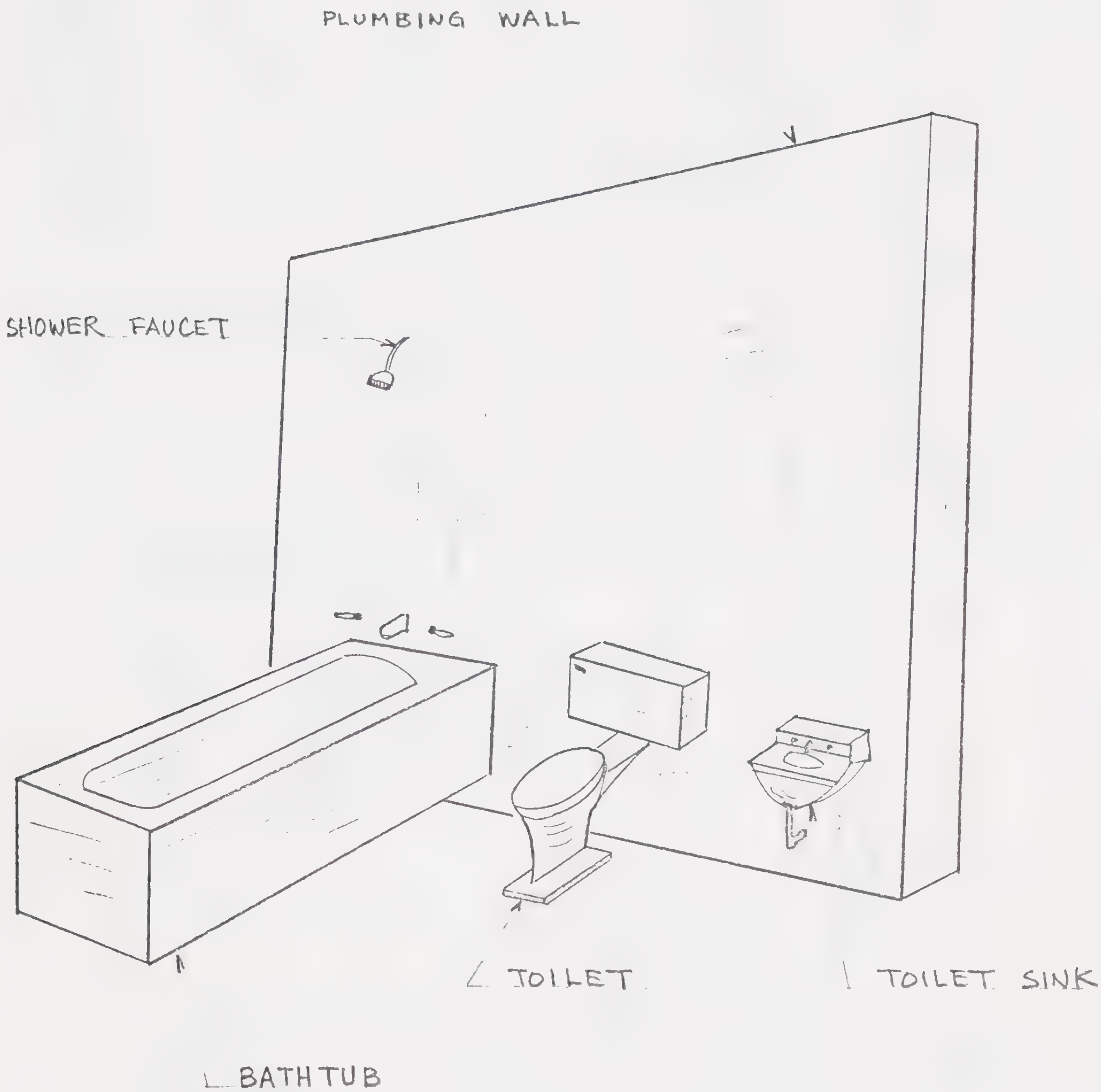
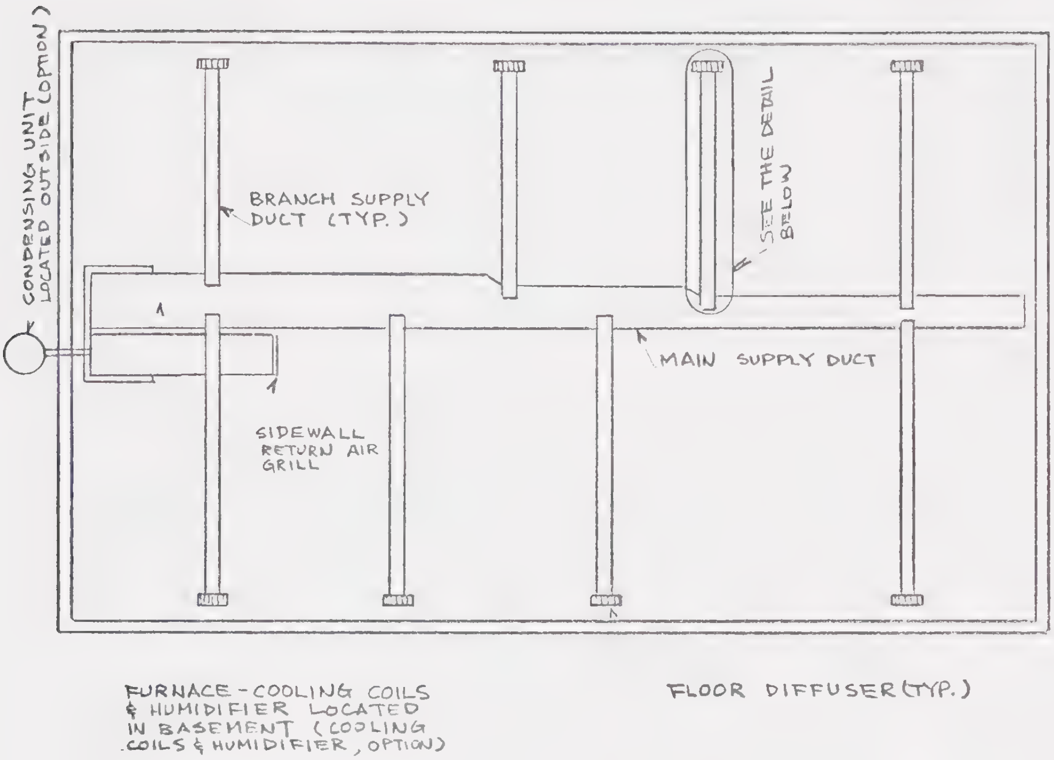


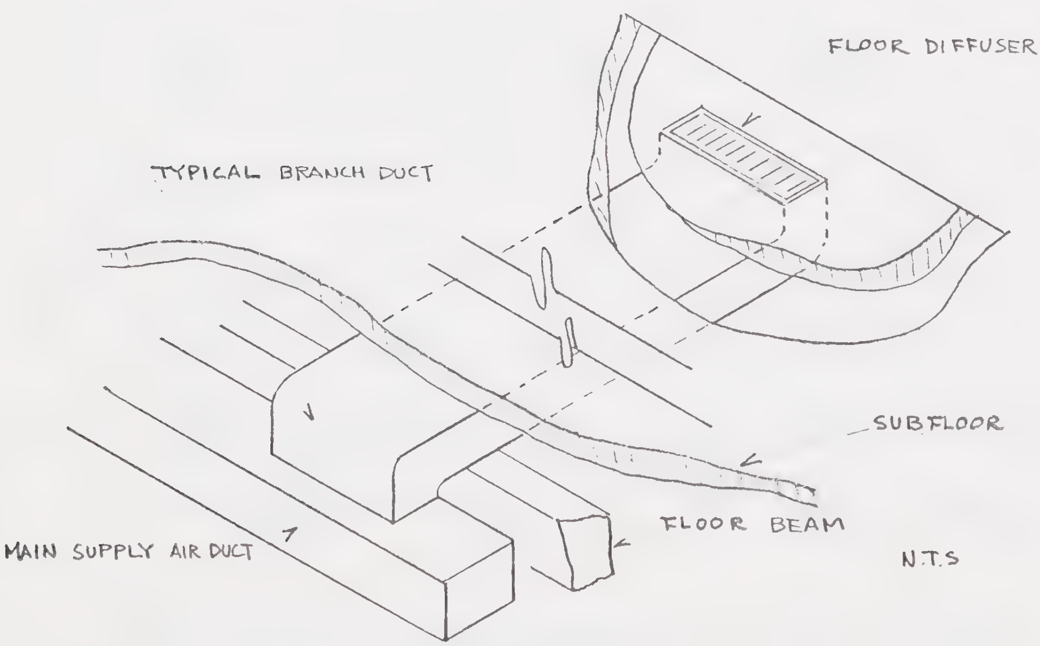
FIGURE 4.2 BATHROOM ASSEMBLY



NOTE : (1) MAIN DUCT TO RUN ALONGSIDE MAIN SUPPLY BEAM ON BASEMENT CEILING

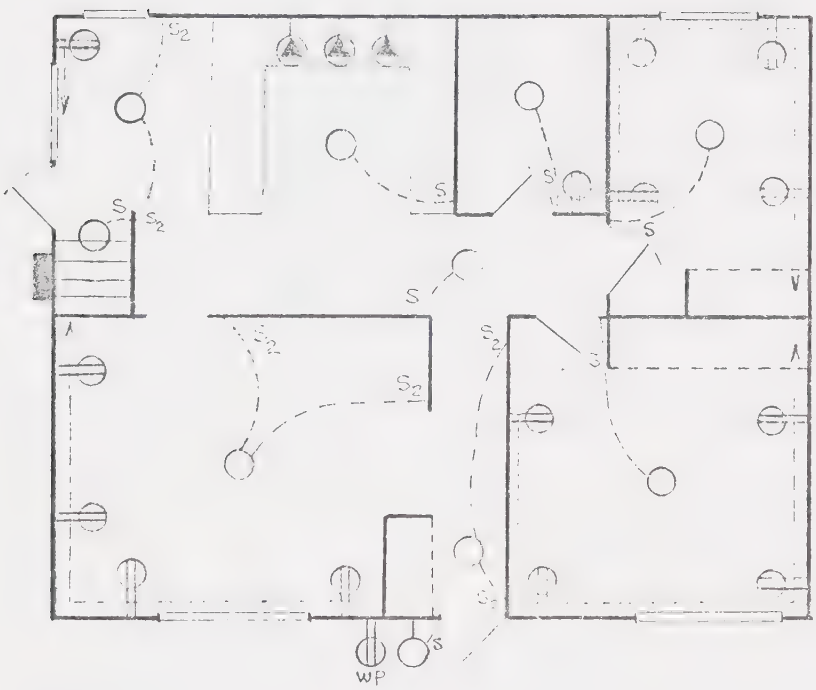
(2) BRANCH DUCTS TO BE RUN BETWEEN FLOOR JOISTS

N.T. S



N.T.S

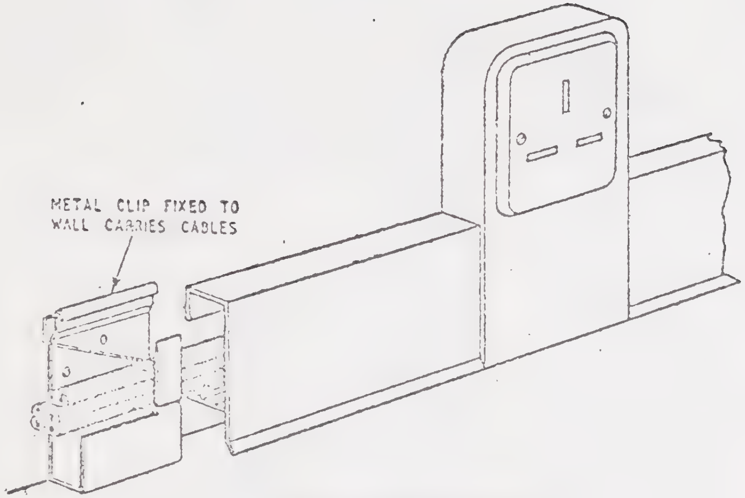
FIGURE 4.3 TYPICAL HEATING LAYOUT AND DUCT INSTALLATION



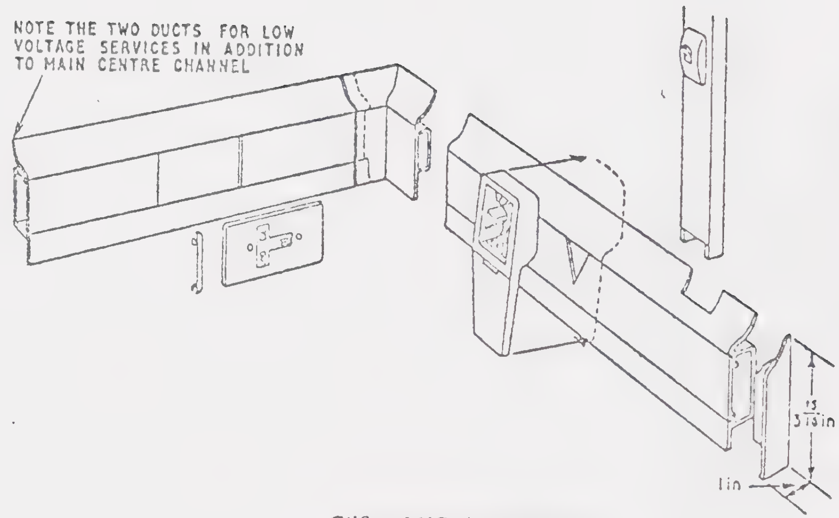
SYMBOLS

- CEILING OUTLET
- WALL OUTLET
- WP WEATHER PROOF CONVENIENCE OUTLET
- DUPLEX CONVENIENCE OUTLET
- S SINGLE POLE SWITCH
- S_2 DOUBLE POLE SWITCH
- SPECIAL PURPOSE OUTLET
- LIGHTING PANEL

FIGURE 4.4 A TYPICAL ELECTRICAL WIRING SYSTEM FOR THE DWELLING



Hartley plastic wiring skirting



Gilflex PVC skirting system

FIGURE 4.5 EXAMPLES OF SKIRTING WIRING

The ceiling outlets and cables above the ceiling to connect these outlets to the lighting panel are installed in the conventional manner.

The rest of the electrical wiring can be accomplished using skirting wiring. This method was chosen due to:

1. Applicability to the dwelling;
2. Cost compatibility to the conventional method (see the estimate cost in Table 4.1); and
3. Flexibility for expansion.

An example of skirting wiring is illustrated in Figure 4.5. This skirting wiring provides ducts in which cables are installed. The ducts are located on the floor against the wall.

As shown in Figure 4.5, electrical branching is accomplished by means of switches and receptacles at convenient locations along the main cables.

The connection between the skirting wiring system and the lighting panel can be done in the conventional manner, that is, the cables are installed under the floor through the floor joists.

4.4 Cost Estimates for the System and the Related Facilities

The cost of plumbing, heating and ventilation, and electrical wiring are based on a floor area of 720 square feet.

The cost of wiring is estimated based on Figure 4.4 and shown in Table 4.1.

Table 4.1 The Wiring Cost Estimates

DESCRIPTION	MATERIAL COST	$ FOB EDMONTON	LABOR	MAN-HOURS
Fixtures		50.00	0.73 MH x 8	= 5.84
Panel 24 circuit Westinghouse GLC-24		32.70	1.5 MH x 1	= 1.5
Boxes & Receptacles Wiremold 2141 & 2.27 GA	(@2.16+@3.77) x14	83.02	0.40 MH x 14	= 5.6
Wall outlet		5.00	1.0 x 1	= 1
Weather proof convenience outlet		10.00	1.0 x 1	= 1
Single pole switches Wiremold 2140	@4.83 x 5	24.15	0.4 x 5	= 2.0
Double pole switches	@6.50 x 3	19.50	1.0 x 3	= 3.0
Cable 100 A service Westinghouse 2-12 Aluminum	@84/100 ft x 600 ft.	50.40	Included in Others	
Mold Wiremold 2100B(1-1/4"x7/8")	@35.40/100 ft. x 90 ft.	31.86	Included in Others	
TOTAL	APPROX.	306.63 $307.00	APPROX.	19.94 20.00
Direct Material				$307.00
Direct labor	$6.35/hr. x 20 man-hours			$127.00
Overhead	50% x direct labor cost			$ 64.00
Total Cost				$498.00

Table 4.2 Cost Estimates for the Service Facilities and Associated Materials

Description	Estimated Cost, $ FOB Edmonton
Plumbing (material and labor)	500
Bathroom unit, Crane, FUTURA model 200 CSA is not obtained yet	760
Kitchen unit, wall and base cabinets complete with steel sink and faucet, 72" ensemble	200
Heating and ventilation* A furnace, necessary ducting and installation	800
Electrical wiring (See Table 4.1 for detail) Wire Mold produced by Conduits National Co. Ltd.	498
Total	$2,758

* Option — $1,310

Air condition equipment LENNOX HS261 including an outside condensing unit, humidifier and air cleaner, installation cost excluded.

CHAPTER V

THE MANUFACTURING FACILITY

The layout of the manufacturing facility basically requires the following steps:

(1) Product design and blueprint development;

(2) The development of a material list;

(3) The development of process flow charts;

(4) Equipment selection;

(5) Facility layout;

(6) Equipment installation; and

(7) Start-up.

Product design has been discussed in Chapter II. The blueprints are developed and shown in Figure 2.1, 2.2, and 2.3.

The panel is composed of steel skins and a honeycomb kraft paper core impregnated with urethane. Table 5.1 represents the material list for one square foot of this panel.

5.1 The Production Process

The total production process requires lock-forming of the inner and outer skins to produce sheets 7'10" in width. Urethane foam is injected between these skins and the expanded paper honeycomb core just prior to the components being simultaneously passed through a steel conveyor system to produce the finished panel.

Table 5.1 The Material List for One Square Foot of Panel

PART NO.	DESCRIPTION	WEIGHT PER SQ. FT.	QUANTITY REQUIRED	UNIT COST FOB EDMONTON	MATERIAL COST	REMARKS
1	Stelcolor prefinished sheet steel, 22 gauge or equivalent	1.25 lbs.	2	$0.2/lbs.	$0.5	Coil width 4 ft.
2	Honeycomb kraft paper 99(11)1, 1 in cell, Union Camp, or equivalent	0.278 lbs.	1	$0.0306/ sq. ft.*	$0.0306	*Based on a 3 in. thickness tax included
3	Urethane, polyite component A component B	0.2 lbs.	-	$1.10/lbs.**	$0.22	**Tax included
4	Adhesive 3M's EC-1828	—	0.0052 ft^3	$32.25/$ft^3$***	$0.168	*** Tax included
				TOTAL	$0.9186	

A detailed description of this process involves:

(1) The development of process flow charts;

(2) A description of the chemical reactions involved in the production of rigid urethane;

(3) Lock-forming of the steel skins;

(4) Expanding the honeycomb paper core; and

(5) The foaming of the finished panel.

5.1.1 The Development of Process Flow Charts

The operation process chart is defined as "a graphical representation of the points at which materials are introduced into the process, and of the sequence of inspections and all operations except those involved in materials handling. It may include information considered desirable for analysis such as time required and location" [21].

The operation process chart for the panel manufacture was developed and is shown in Figure 5.1.

5.1.2 Rigid Urethane Foam Production

Urethane foam is essentially a combination of polyol, catalysts and surfactant.

To foam rigid 2.0 pounds per cubic foot density urethane, the component A and B of "POLYLITE" manufactured by Reichhold Chemicals, Inc. will be mixed at the mix ratio 1:1 by weight.

The manufacturing process must consider three basic times. They are referred to as:

(1) Cream time (from the start of mixing, requires 25 sec.-35 sec.

(2) Rise time (from the start of mixing) requires 2 min. 30 sec.- 3 min.-30 sec.

(3) Tack-free time (from the start of mixing) requires 2 min. 45 sec.- 3 min. 45 sec.

Observed at 77° F.

Cream time is the start of exothermic reaction manifested by the milky appearance of the foaming mass.

Rise time is the completion of foaming expansion.

Tack free time is the completion of hardening of the mass.

5.1.3 Lock-Forming the Steel Skins

Steel coils are not available in ninety four inch widths, therefore, two coils of forty eight inch width have to be lock-formed to produce a final width of 94 inches.

Two steel coils, 22 gauge material, are placed on the uncoilers. The steel sheets are fed into a lock-former in order to lock-form the edges of the steel sheets.

The pebble pattern is required on the outside surface of the bottom half of the exterior wall panel. This is performed by a roll former prior to the lock-former. When the interior wall panels are produced, the pebbling process is omitted.

5.1.4 Expanding the Honeycomb Paper Core

Unexpanded slices of honeycomb paper are fed into a honeycomb expander and curer. This process is illustrated in Figure 5.2. Because the honeycomb expander and curer can handle a maximum width of only four feet, the sheet of expanded and cured

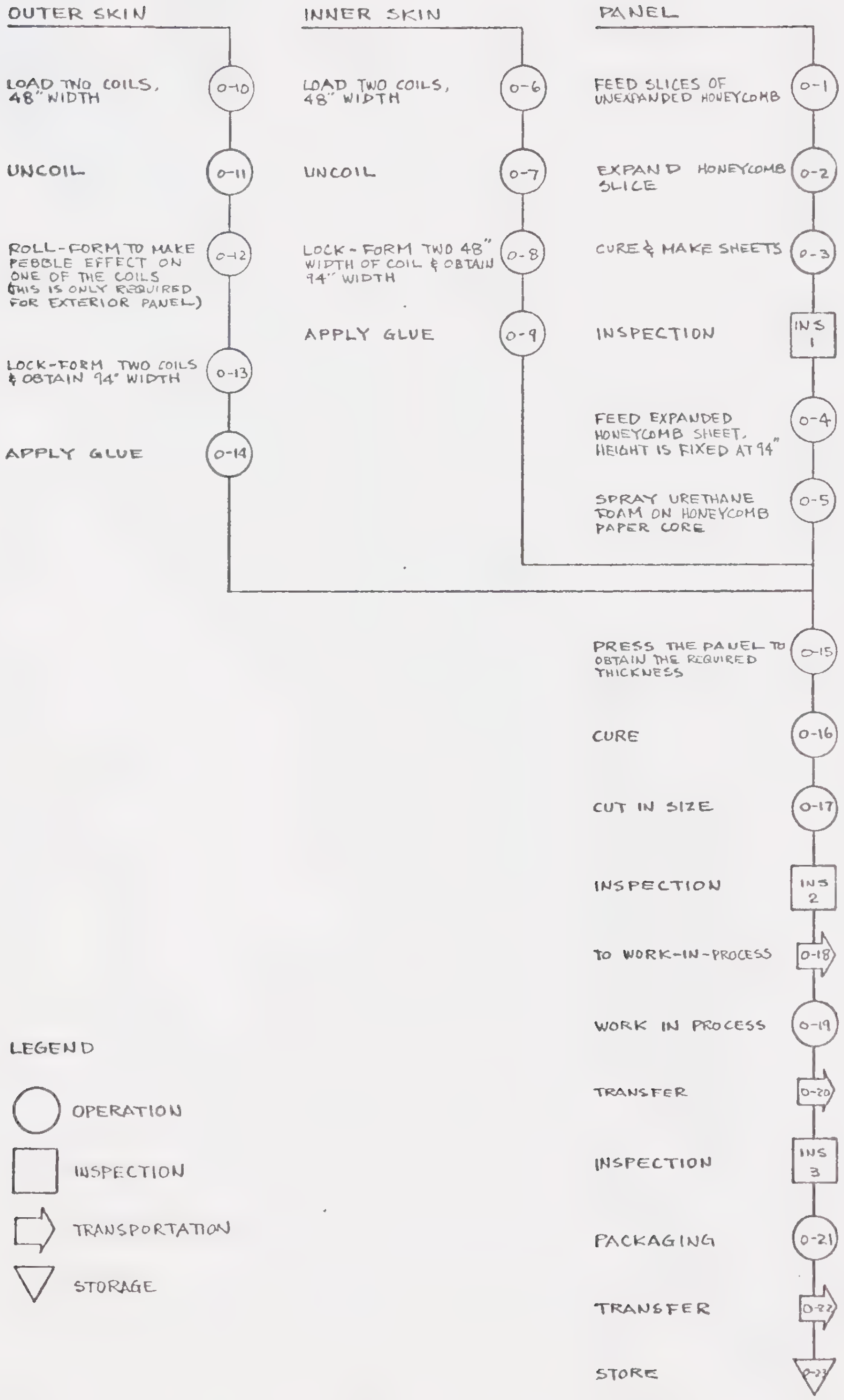


FIGURE 5.1 THE OPERATION PROCESS CHART TO MANUFACTURE WALL PANELS

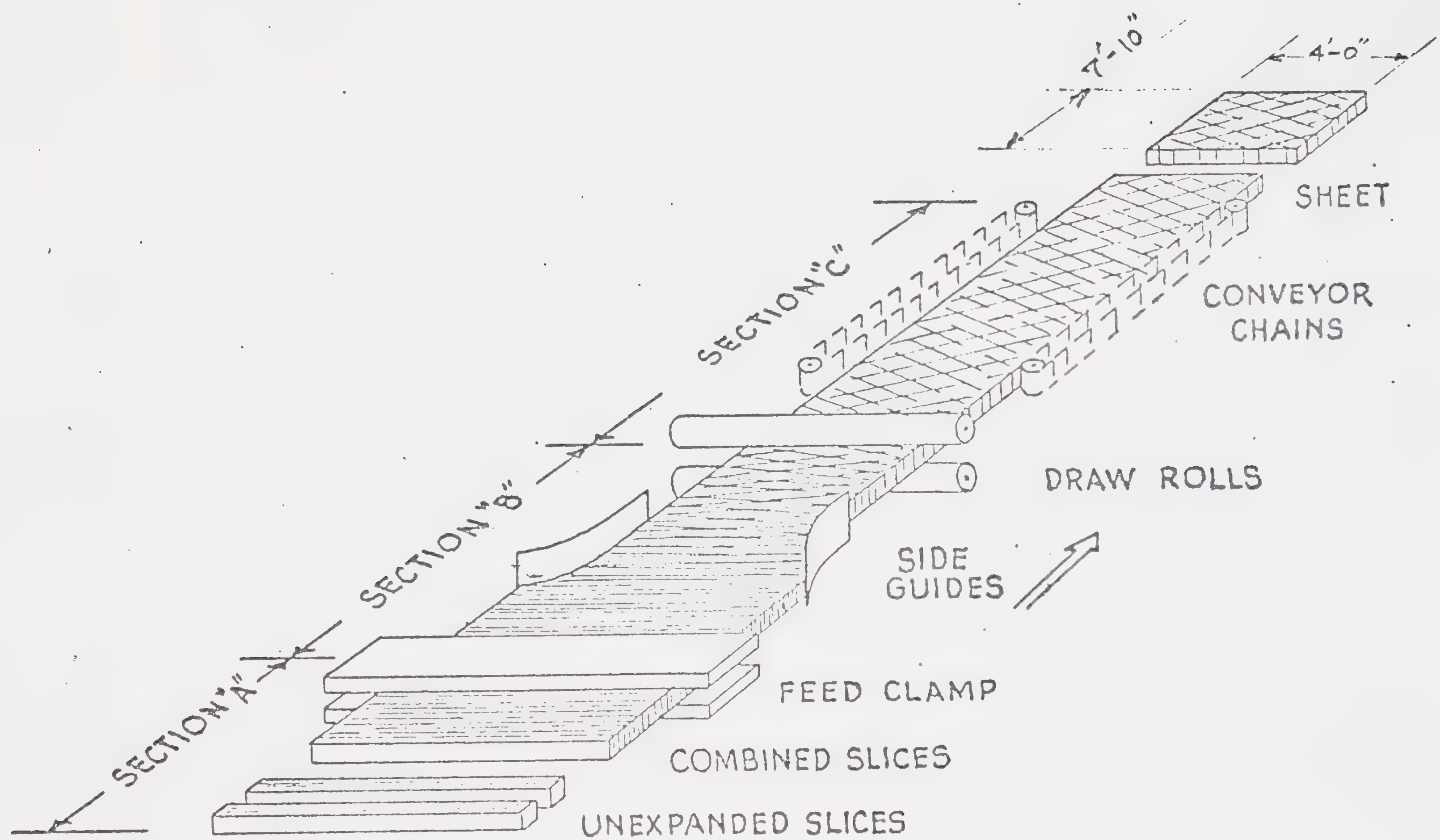


FIGURE 5.2 ILLUSTRATION OF HONEYCOMB PAPER EXPANDING PROCESS

honeycomb paper is cut into sheets 7' - 10" x 4' -0". These sheets are fed onto a conveyor so that adjacent sheets are put together along the 7' -10" side.

5.1.5. The Foaming of the Finished Panel

The foaming of the finished panel involves three processes:

(1) Application of glue to the steel skins;

(2) Dispensing urethane foam to the honeycomb paper core; and

(3) Laminating of the steel skins and core material.

After the steel sheets comprising the two skins are lock-formed, a layer of glue is applied in order to facilitate bonding with the honeycomb paper core by a glue applicator.

In the final analysis, an experimental study would be necessary to determine the type of glue to be used to give optimal bonding qualities between the urethane core and steel skins.

The glue applicator consists of a roll, a glue depositor and an air pressured glue tank. Glue is stored in the air pressured glue tank and is transferred by air pressure to the glue depositor through a tube. The glue depositor has many small holes longitudinally adjacent to the roll spaced at one sixteenth of an inch so that glue is easily deposited on the roll.

The lock-formed steel sheets are running on the roll so as to apply glue on the surface for bonding to the honeycomb paper core. The schematic of the glue applicator is shown in Figure 5.3.

The honeycomb paper core is conveyed from the honeycomb expander and curer. Two nozzles for foam dispensing are provided

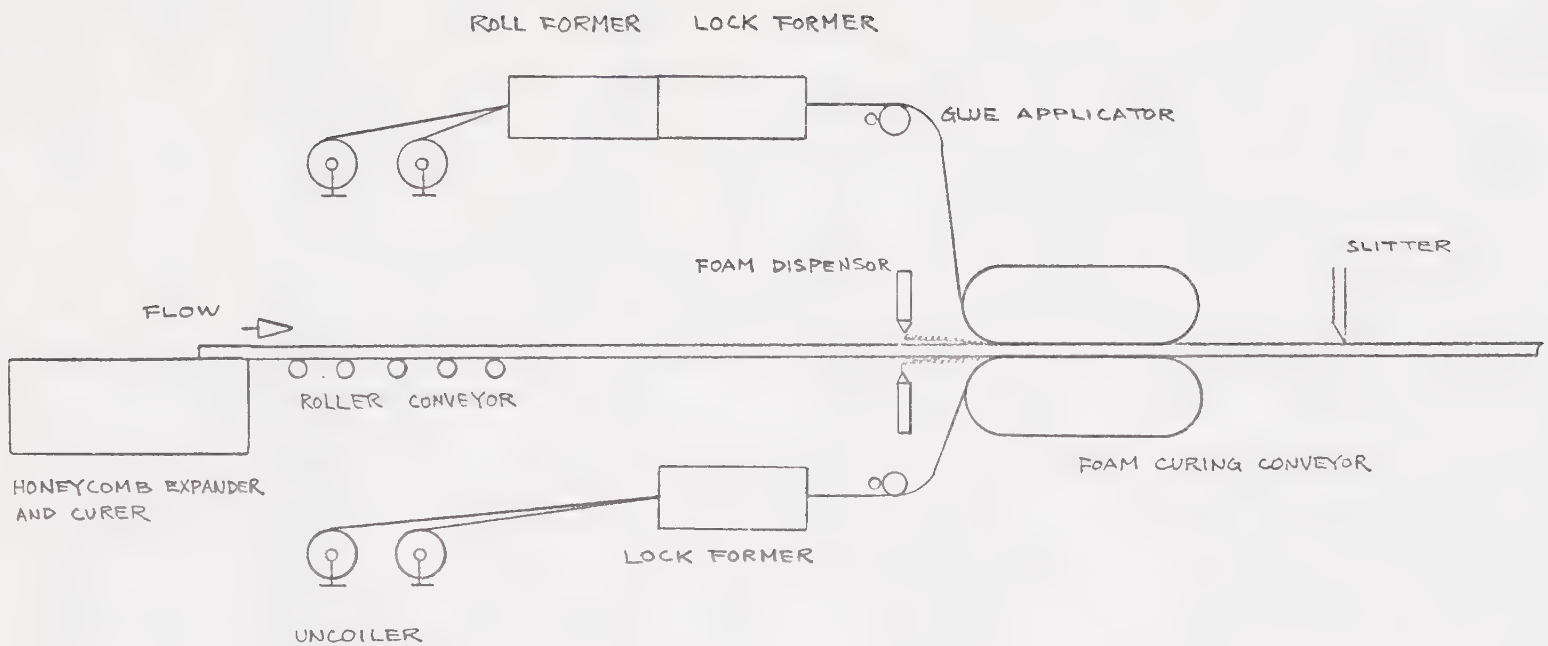
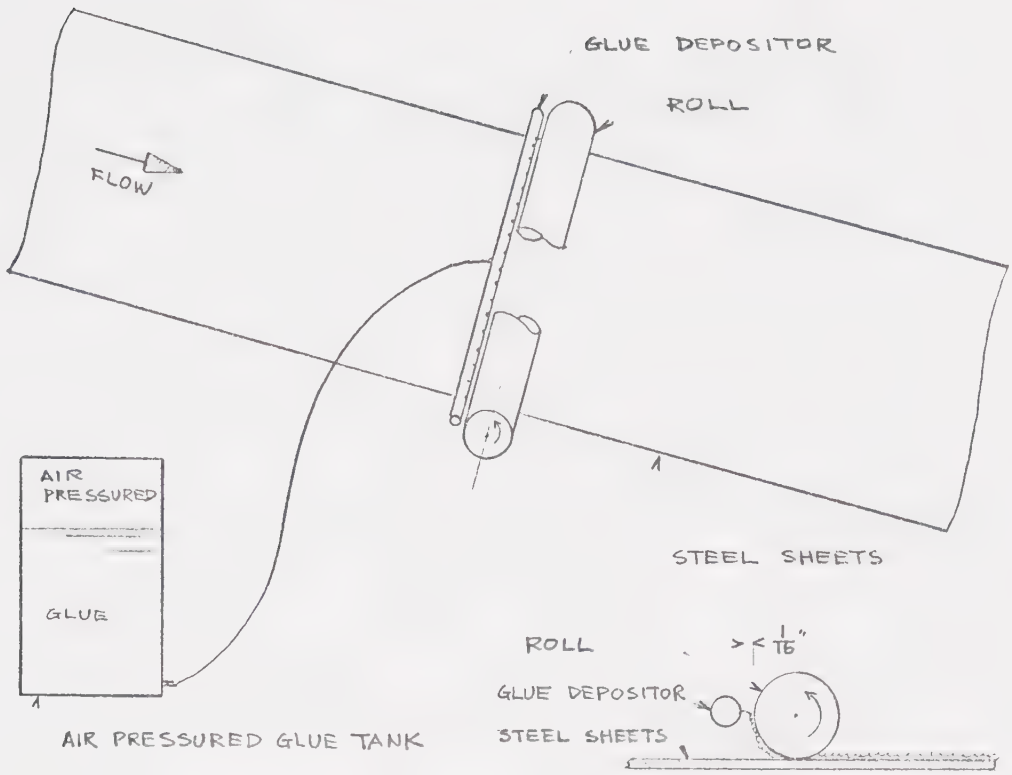
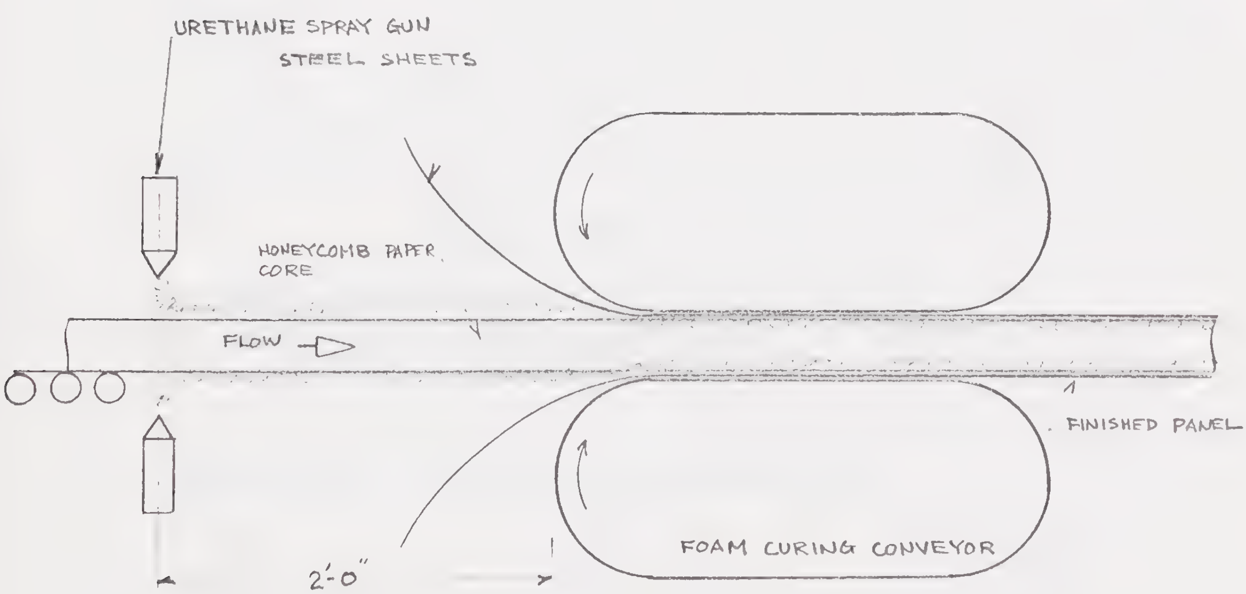


FIGURE 5.3 A SCHEMATIC DRAWING OF THE PANEL MANUFACTURING PROCESS

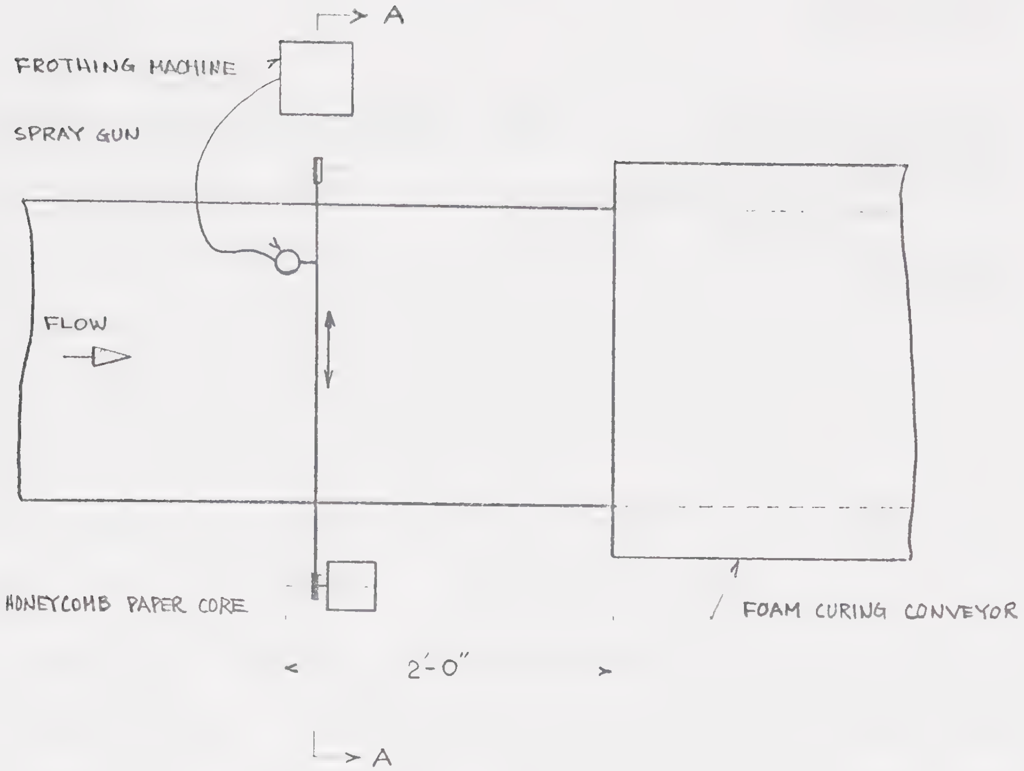


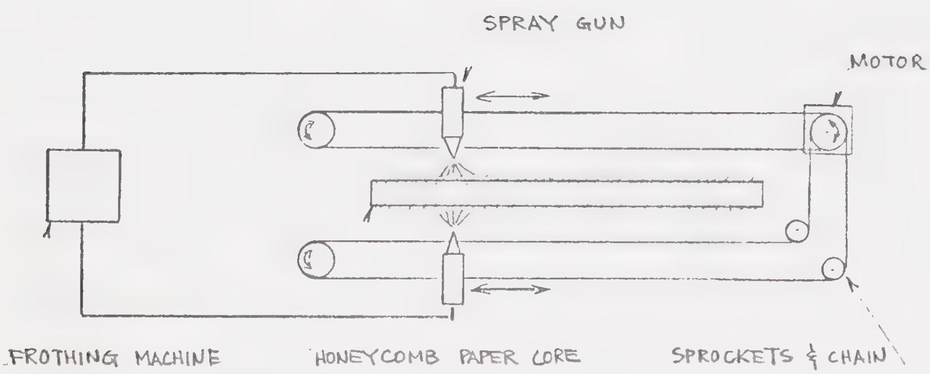
GLUE APPLICATOR SCHEMATIC



PANEL SANDWICHING SCHEMATIC

FIGURE 5.3 CONTINUED





SECTION A-A

URETHANE FOAM IS SPRAYED ON THE HONEYCOMB PAPER CORE WHEN THE SPRAY GUNS MOVE FROM RIGHT TO LEFT ONLY. THE SPEED OF MOVEMENT OF THE SPRAY GUNS IS ADJUSTED SO AS TO DISPENSE URETHANE FOAM UNIFORMLY ON THE CORE.

DISPENSING URETHANE FOAM SCHEMATIC

FIGURE 5.3 CONTINUED

to dispense urethane foam to both sides of the honeycomb paper core. The nozzles undergo an oscillatory sweeping motion across the full width of both sides of the core in order to deposit a uniform layer of urethane foam on each core face (See Figure 5.3 for details).

The steel skins with glue applied and the honeycomb paper core with urethane foam deposited on both sides are fed into the foam curing conveyor. The urethane, at this stage, has not yet hardened. Therefore, when the steel skins and the core are sandwiched, or laminated, in the foam curing conveyor the urethane foam is pressed by the conveyor and squeezed into the cells of the honeycomb paper core (see Figure 5.2 for the details). The foam curing conveyor is designed with sufficient length to allow the urethane to harden into a rigid mass and form a completed panel of the required thickness. The finished panel is then cut into any desired length. These panels are conveyed to work-in-process to install windows and doors and for final finishing. The final finished panels are then packaged and stored in the warehouse for shipment to location.

5.2 Normal Time Calculations

In order to complete the factory layout arrangements, normal time values have been calculated. Normal time values make it possible to determine the curing conveyor length, equipment selection for the production line and manpower requirements.

Normal time is defined as the time required by a qualified workman, working at a pace which is ordinarily used by workmen, when capably supervised, to complete an element, cycle, or operation [22].

The following assumptions were made:

(1) There are 250 working days per year.

(2) Normal shift = 8 hours.

(3) Scrap allowance = 5%.

(4) Shop efficiency = 80%.

(5) Rating factor = 100%.

(6) Number of channels = 1.

(7) Personal allowances = 48 minutes/day.

(8) Fatigue allowance = 5%.

(9) Annual production rate = 500 homes.

(10) Additional panels for extension = 20% of net production rate per day.

Net production rate per day = 198 linear feet/home*

$$\times \frac{500 \text{ homes}}{250 \text{ working days per year}} = 396 \text{ linear feet of panel.}$$

Production rate per day

= (396 + 396 x 0.2) x 1.06

= 504 linear feet of panel

Total allowance

$$= \frac{48 \text{ min.}}{8 \text{ hours} \times 60 \text{ min.}} \times 100 + 5\% = 15\%$$

Shop planning time

$$= \frac{8 \text{ hours} \times 60 \text{ min.}}{504 \text{ ft.}} = 0.9524 \text{ min./linear foot}$$

= 57.14 sec./linear foot

---

* See Table 6.1

Standard time

= Shop planning time x shop efficiency

= 0.9524 x 80%

= 0.762 minutes/linear foot

$$\text{Normal time} = \text{standard time} \left(1 - \frac{\text{allowance \%}}{100}\right)$$

$$= 0.762 \left(1 - \frac{15}{100}\right)$$

$$= 0.762 (1 - 0.15)$$

= 0.648 minutes/linear foot

(= 1.543 ft./min.)

Normal time to produce one linear foot of panel which is 7' - 10" in height is determined as 0.648 minutes (38.88 seconds).

5.3 Determination of Foam Curing Conveyor Length for the Production Line

The length of the foam curing conveyor depends upon two factors, the urethane foam chemical reaction time and the speed of the foam curing conveyors.

The conveyor speed was calculated to be 0.648 min./linear ft. of panel = 1.543 ft./min. in Section 5.2. This enables one to calculate the necessary conveyor length because one of two factors is known and fixed.

The chemical reaction time, cream time, rise time and tack-free time described in Section 5.1.2, the time to complete all chemical reactions, is two minutes and forty-five seconds to three minutes forty-five seconds based on a temperature of 77° F. Some allowance needs to be included.

Final chemical reaction time

= Chemical reaction time + Allowance

= 3 min. 45 sec. + 30 sec.

= 4 min. 15 sec.

The future production increase is estimated to be 50%. Therefore, the conveyor length is:

150% x 1.543 ft./min. x 4-15/60 min.

= 1.5 x 1.543 x 4.25

= 9.8 ft $\doteqdot$ 10 ft.

5.4 The Chosen Equipment for the Plant

The equipment to manufacture the panel is chosen to meet the requirement which has been discussed in the proceeding section and is summarized in Table 5.2. The installation cost estimates for the chosen equipment are given in Table 5.3. The detailed description of the equipment is provided in Appendix D.

Table 5.2 A Summary Table of the Chosen Equipment on the Production Line

Equipment	No. Required	Unit cost FOB Edmonton	Initial Cost $	Life Yr.	Salvage Value in 5 yrs.	Maintenance Cost $/yr.	SLD* $/yr.	Remarks
Honeycomb expander and curer, Union Camp	1	18,765	18,765	10	9,000	500	1,953	
Uncoiler, model J 481 Elkhart Welding & Boiler Works	4	6,225	24,900	15	8,300	1,000	3,320	
Lock-former General Metal	2	2,000	4,000	15	3,000	500	200	
Foam Curing Conveyor	1 set	1,000	1,000	10	500	250	100	
Foaming machine	1	16,000	16,000	10	8,000	2,000	1,600	
Slitter	1	3,000	3,000	10	1,500	300	300	
Pebble Pattern Roll Former General Metal	2	2,000	4,000	15	3,000	500	250	
Roller conveyor with a kick-off device hydraulic operated	1	2,600	2,600	10	1,300	200	260	
Kick-off device hydraulic operated	2	1,000	2,000	10	1,000	100	200	
Roller conveyor partially motorized	182 ft.	9,100	9,100	10	4,500	100	1,020	
Glue applicator	2	1,000	2,000	5	1,000	200	200	
Working table	1	2,000	2,000	10	1,000	100	200	
Circular saws with a jig	2	750	1,400	5	0	200	280	
Overhead crane 5 ton 35 ft. span Canadian Monorail	1	13,000	16,000	10	8,000	500	1,600	Installation $3000 Sales tax included FOB Edmonton Hoist bridge electric control device
Overhead crane 2 ton, 35 ft. span Canadian Monorail	1	7,500	8,700	10	4,350	300	870	Installation $1200 Sales tax included FOB Edmonton Electric control device
Storage bins	1 set	500	500	5	0	100	100	
Office furniture & Equipment		10,000	10,000	10	3,000	200	1,400	
Miscellaneous		10,000	10,000	5	0	500	2,000	
			135,965		57,450	7,550	15,853	

* SLD = Straight Line Depreciation

Table 5.3 The Installation Cost Estimates

Equipment	No. Required	Unit Weight	Total Weight	Man-hour 40 MH/Ton	
Honeycomb expander and curer	1	7,800	7,800	156	
Uncoiler	4	1,000	4,000	80	
Lock-former	2	500	1,000	20	
Foam curing conveyor	1 set	1,500	1,500	30	
Foaming machine	1	1,000	1,000	20	
Slitter	1	100	100	2	
Pebble pattern roll former	2	500	1,000	20	
Roller conveyor with a kick off	1	3,000	3,000	60	
Kick off device hydraulic operated	2	200	400	8	
Roller conveyor partially mortorized	1 set	27,000	27,000	540	
Working table	1	1,000	1,000	20	
Circular saws with a jig	2	250	500	10	
Overhead crane, 5 tons	1				$3,000
Overhead crane, 2 tons					1,200
			Total man-hour	966	4,200

(1) Direct labor	966 M/H x @$4.50/hr.	4,347	
		4,200	8,547
(2) Direct material	10% of (1)		854
(3) Overhead	50% of (1) + (2)		4,700
(4) Profit	20% of (1) + (2) + (3)		2,820
	Total installation cost		$16,921

CHAPTER VI

INVENTORY FOR RAW MATERIALS AND FINISHED GOODS

The basic problem with respect to inventory is:

(1) To decide when and how much to order; and

(2) To decide when and how much to manufacture

The optimal inventory quantity has to be determined to give satisfactory service to customers, to reduce costs and to maintain a minimum of capital tied-up in inventory. Inventory cost can appreciably affect the profitability of the organization.

6.1 The Inventory for Finished Goods

Since the assumption is made that the production facility produces five hundred homes per year, the plant needs to have enough space for finished goods to meet this requirement.

It is estimated that this particular dwelling design will need three to five days to erect and completely finish. Therefore, assuming constant inventory usage, five days of finished goods, ten dwellings, should be kept in the warehouse and readily available for the customer.

Table 6.1 gives the total panel requirements per home in linear feet.

Table 6.1 The Panel Requirement per Home in Linear Foot

Panel	Length	No. Req'd	Length Req'd (ft)
Exterior	14'-8-1/2"	4	58.83
Exterior	11'-8"	4	46.67
Interior	12'-0"	3	36.00
Interior	8'-6"	1	8.50
Interior	7'-9-1/2"	1	7.79
Interior	5'-6"	1	5.50
Interior	4'-0"	4	16.00
Interior	2'-0"	3	6.00
Side Triangular	12'-3"	1	12.25
	Total Panel Length Required		197.54 ft.
			≒ 198 linear feet/home

The necessary warehouse space is estimated as follows with the assumption that the panels for two homes can be vertically stacked.

Base: The largest panel size 15'-0" x 7'-10"

Space required for the stack

=[(14'-8'1/2") + aisle] x [(7'-10") + aisle]

=[(14'-8-1/2") + (2'-6")] x [(7'-10") + (2'-6")]

=(17'-2-1/2") x (10'-4")

=178 square feet

The space for ten dwellings

=178 sq. ft. x 5 = 890 sq. ft.

The final space requirement equals:

The space for ten dwellings + a 50% future production increase

= 890 sq. ft. + 890 sq. ft. x 0.5

= 1,335 square feet.

6.2 The Raw Materials Inventory

In order to determine the optimal lot size for raw materials and estimate the warehouse space requirements, the elementary economic lot size model was used. Using the production rate of five hundred homes per year and constant demand for homes throughout the year, the use of elementary economic lot size model seems reasonable.

The elementary economic lot size model makes the following assumptions:

(1) Items are assumed to be withdrawn continuously and at a known constant rate;

(2) Items are ordered in equal numbers at a time;

(3) Material shortages are not allowed;

(4) Unit cost is constant per item;

(5) Inventory holding costs are constant per unit of time and include total holding costs, interest and warehouse costs, etc.,

(6) Preparation costs (cost of placing an order or getting an order) are constant per order; and

(7) Zero lead time is required.

Under these assumptions the optimal lot size is given by the following equation:

$$Q_o = \sqrt{2C_pR/C_H}$$

where Q_o = Optimal lot size

C_p = Preparing cost per order, assumed to be \$7

R = Annual requirements in units

C_H = Inventory holding cost per unit per year, assumed to be 20% of the unit cost.

All raw materials needed for production are listed and the optimal lot size is computed in Table 6.2 and 6.3.

Table 6.2 Annual Requirement of Direct Material

Item	Unit Cost	Material per home with scrap allowance	Annual Requirement	Annual Material Cost $
Polylite Component A Component B	\$1.10/lbs.	369 lbs.	184,500 lbs.	202,950
Pre-finished steel, 22 gauge	\$0.2/lbs.	4710 lbs.	2,355,000 lbs.	471,000
Kraft honeycomb paper, Union Camp	\$0.0306/ft^2	1845 ft^2	922,500 ft^2	28,229
Adhesive 3M EC-1828	\$32.25/ft^3	9.59 ft^3	4,795 ft^3	154,639
Aluminum door, window	\$2.25/ft^2	169 ft^2	84,500 ft^2	190,125
Miscellaneous 1% of the annual material cost	1,046,943 x 0.01			10,469
	Total annual material cost			\$1,057,412

Table 6.3 A Summary Table of Direct Material and Warehouse Space Requirement

Item	Unit cost FOB Edmonton	Annual Requirement	Inventory Holding Cost	Theoretical Optimal Lot Size	Limitation	Final Optimal Lot Size	No. of Orders Per Year	Estimated Warehouse Space	Remarks
Polylite Component A Component B	\$1.10/lbs.	184,500 lbs.	\$0.22	3,427 lbs.	918 lbs/ drum	3,672 lbs. (4 drums)	50	(3'x3')x4 = 36 ft^2	
Pre-finished steel sheet, 22 gauge	\$0.2/lbs.	2,355,000 lbs.	\$0.04	*258,082 lbs. (28,710 lbs)	9600 lbs/ coil 157,000 lbs/ rail car	259,200 lbs. (27 coils)	9	12'x60' = 720 ft.	*40 days delivery
Honeycomb-Kraft paper, Union Camp	\$0.0306/ ft^2	922,500 ft^2	\$0.00612	45,938 ft^2	157,000 lbs/ rail car	45,938 ft^2	20	45'x12' = 540 ft^2	30 days delivery
Adhesive 3M EC-1828	\$32.25/ ft^3	4,795 ft^3	\$6.45	102 ft^3 (17 imp. gal)	1100 lbs. 1/2 ton truck	270 ft^3 (1 drum)	18	3'x3' = 9 ft^2	
Plastic baseboard	\$0.15/ ft.	107,400 ft.	\$0.03	7,080 ft.	300 ft/ carton 2'x2'x2'	7,200 ft. (24 cartons)	15	10'x10' = 100 ft^2	
Aluminum doors & windows (supplied by a local manufacturer)	\$2.25/ft^2	84,500 ft^2	\$0.45	162 $ft.^2$	1100 lbs/ 1/2 ton truck	**676 ft^2	125	12'x12' = 144 ft^2	**Two days production material
Miscellaneous								64 ft^2	
					Total			1,613 ft^2	
					Estimated future increase 50%			807	
					Final space requirement			2,420 ft^2	

CHAPTER VII

CASH FLOW CALCULATION

Cash flow calculations are necessary in order to come up with the cost per home and determine the monthly payment for the home. These calculations, in the final analysis will determine whether or not this particular dwelling can meet the demands for housing of the low-to-medium income family.

The revenue requirements approach has been used in this study which require calculations to determine the total annual equivalent costs (AEC) necessary to:

(1) Repay the investors original capital investment at some acceptable interest rate (referred to as the after-tax cash flow requirement - ATCFR);

(2) Meet annual income tax payments; and

(3) Meet all operating costs.

Notation:

$(a/p)_n^i$ = Annual equivalent of a present sum (p) at interest rate (i) for the next (n) years.

$(a/f)_n^i$ = Annual equivalent of a future sum (f) at interest rate (i) for the next (n) years.

ATCFR = After-tax cash flow required for the year.

IT = Income tax

AEDE = Annual equivalent depreciation expense

CCA = Capital Cost Allowance

MARR = Minimum Attractive Rate of Return

i_d = Interest rate paid on the debt capital

i_e = Interest rate paid on the equity capital

r = Debt ratio

i_c = Cost of the composite capital

ϕ = Income tax factor

7.1 Capital Cost Estimates

The total capital requirements for a new manufacturing plant can be broken down into the following components for estimating purposes.

(1) Depreciable investment

- (a) Building and utilities
- (b) Equipment, including installation cost
- (c) Others

(2) Other investments

- (a) Research and development
- (b) Engineering
- (c) Startup costs
- (d) Others

(3) Non-depreciable capital requirements

- (a) Land
- (b) Working Capital

  Cash, receivables and inventory.

The estimates are made based on the plant layout in Appendix E.

Building

Office $\$15/ft^2 \times (88\ ft \times 40\ ft)$ = 52,800

Plant $\$10/ft^2 \times (80\ ft \times 212\ ft)$ =169,600

$222,400

Life = 20 years

Salvage value in 20 years (estimated) = $30,000

Salvage value in 5 years = Book value (assumed)

$$= 222,400 - \left(\frac{222,400 - 30,000}{20} \times 5\right)$$

$$= 222,400 - (9,620 \times 5)$$

$$= 222,400 - 48,100 = 174,300$$

Land

$$(200\ ft \times 300\ ft) \times \frac{\$15,000/acre}{43,560} = \$20,660$$

The salvage value in 5 years remains the same.

Working Capital Requirements for Panel Manufacturing

Working capital is defined as the excess of current assets over current liabilities.

When the dwellings are financed by Alberta Housing Corporation, the payments are fully made to building contractors if the dwellings are completed within thirty-five days.

It is estimated that the construction takes seven days (three days for the excavation and concrete foundation, and four days for the dwelling erection).

Therefore, the capital tied up with respect to the payments to contractors will be decreased. This system requires less

working capital than is presently required for conventional housing.

In order to determine the working capital requirements for panel manufacturing the assumptions are made:

(1) Twenty working days per month;

(2) Thirty days outstandings on accounts receivable; and

(3) Twenty percent profit

Profit* = 20% (Direct Material + Direct Labor + Overhead)

= 0.2 x (1,057,412 + 64,848 + 144,310)

= 253,314

Therefore, the estimated panel selling price per home:

$$\frac{\text{Cost + Profit}}{\text{No. of homes}} = \frac{1,266,570 + 253,314}{500} = \$3,040/\text{home}.$$

Direct material and direct labor cost per home:

$$\frac{\text{Direct material + Direct labor}}{\text{No. of homes}} = \frac{1,057,412 + 64,848}{500}$$

= $2,245/home.

---

* A twenty percent markup on manufactured cost is assumed to arrive at working capital.

Current Assets

1.	Account Receivables $3,040 x 20 homes	60,800
2.	Inventories	
	(a) Finished goods (10 homes in stock)	
	$2,245 x 10	22,450
	(b) Work-in-process (2 homes on line)	
	$2,245 x 2	4,490
	(c) Raw materials	
	(1) 40 days steel supply	51,840
	(2) One month chemical components supply	4,039
	(3) One month honeycomb paper supply	1,406
	(4) One month adhesive supply	12,371
	(5) One month aluminum door and window supply	15,210
	(6) 30 days sales tax	
	12% x account receivables = 0.12 x 60,800	7,296
	(7) Packaging materials (see Table 7.2)	6,475
	(8) Office supplies	3,165
	Total	$189,542

Current Liabilities

1.	Accounts payable	
	(a) One month purchases (excluding steel)	
	Chemical components, honeycomb paper, adhesive, aluminum door and window supply	33,026
	(b) Packaging materials	6,475
	(c) Office supplies	3,165
	Total	$42,666

Working capital = Current assets-Current Liabilities

= $189,542 - $42,666 = $146,876

Table 7.1 The Summary of the First Cost,
Salvage Values and Depreciation

Assets	Capital costs $	Salvage values in year five,$	Straight line depreciation
1. Equipment including installation cost	152,886	57,450	19,088
2. Building	222,400	174,300	9,620
3. Land	20,660	20,660	___
4. Working capital	146,876	146,876	___
Total	$542,822	$399,286	$28,708/yr.

7.2 Cash Operating Cost Estimates

The cash operating cost consists of:

(1) Direct material cost;

(2) Direct labor cost; and

(3) Overhead cost

The cash operating costs are estimated and summarized in Table 7.2.

Table 7.2 A Summary Table of Cash Operating Costs

Item	Wage	Total annual cost, $		Remarks
Direct material		1,057,412	1,057,412	*See Table 6.3 for details
Direct Labor				
(1) 4-Machine operators	$4.50/hr.	37,440		Based on 40 hrs/week
(2) 4-Plant workers	$571/Mon.**	27,408	64,848	** Obtained from sixteenth annual report salary and wage survey, Alberta Bureau of Statistics 1st Aug. 1972
Overhead				
Payroll				
(1) 1-President	$20,000/yr.	20,000		
(2) 1-Plant engineer	1,400/Mon.**	16,800		
(3) 1-Plant foreman	910/Mon.**	10,920		
(4) 1-Accountant	860/Mon.**	10,100		
(5) 1-Secretary	480/Mon.**	5,800		
(6) 1-Office clerk	562/Mon.**	6,750		
(7) 1-Warehouseman	510/Mon.**			
(8) 1-Mechanic	4.95/hr.**	10,295		
(9) 1-Janitor	546/Mon.**	6,600		

Table 7.2 (continued)

Item	Wage	Total annual cost, $		Remarks
Insurance				
(a) Fire		5,630		(Equipment + Building)x 0.015
(b) Public liability		5,000		1,000,000 x 0.5%
Compensation		4,747		3% of payroll = 158,233 x 0.03
Power		2,500		See Table 7.3 for details
Maintenance		7,150		See Table 5.2 for details
Building operating & maintenance		3,600		$300/mon. x 12
Packaging materials				
(a)plastic film $25/2000 ft^2		2,475		@ 2 x 198 ft. x $25/2000 ft^2
(b)plastic strip $20/1000 ft.		4,000		@ 400 ft x $20/1000 ft.
Office supplies		3,165		2% of payroll, assumed
Others		12,658		8% of payroll, assumed
			144,310	
Total cash operating cost			1,266,570	

Table 7.3 The Estimates for Power Requirements

Note: This calculation is described in [21]

1) Power load

	KW
Honeycomb expander & curer	100
Uncoiler @ 1.5 KW x 4	6
Lock-former @ 0.75 KW x 2	1.5
Foam Curing Conveyor @ 1.5 KW x 2	3
Foaming machine @ 0.5 KW x 1	0.5
Slitter @ 0.5 KW x 1	0.5
Pebble Pattern Roll Former @ 0.75 KW x 2	1.5
Kick off device @ 0.5 KW x 2	1
Roller conveyor @ 0.5 KW x 20 motors	10
Crane @ 5 HP x 0.75	3.75
@ 3 HP x 0.75	2.25
	130
Miscellaneous 10% of the above	13
Total	143 KW

2) Light Load

Assumption Type of fixture = semidirect fluorescent fixtures consuming 100 watts.

Recommended lighting levels

office 2,208 ft^2 = 150

lunch room 2080 ft^2 = 100

warehouse 6,400 ft^2 = 50

inspection area 800 ft^2 = 50

Table 7.3 (continued)

Recommended lighting levels

work-in-process area 4320 ft^2	=	100
production line 4,672 ft^2	=	30

Footcandles for each watt per square foot for

semidirect fixture = 14

Area	Watts per square foot	Total lighting load, watts
office	150/14 = 10.71	10.71 x 2,208 = 23,648
lunch room	100/14 = 7.15	7.15 x 2,080 = 14,872
warehouse	50/14 = 3.57	3.57 x 6,400 = 22,848
inspection area	50/14 = 3.57	3.57 x 800 = 2,856
work-in-process area	100/14 = 7.15	7.15 x 4,320 = 27,975
production line	30/14 = 2.14	2.14 x 4,672 = 19,998
		102,197 watts

Total annual power requirement

Power load = 143 KW x 8 Hrs x 250 days = 286,000 KWH

Light load = 103 KW x 8 Hrs x 250 days = 206,000 KWH

Car plug in for winter season

= 0.4 KW x 18 cars x 8 Hrs x 60 days

= 3,456 KWH

Annual estimated consumption

= 286,000 + 206,000 + 3,456 = 495,456 KWH

According to the Edmonton Power rate schedule

$$\frac{495{,}456 \text{ KWH}}{12 \text{ mon.}} = 41{,}288 \text{ KWH/Month}$$

$$\frac{5000}{2675 + 41{,}288} \times 0.5 = 0.056 < 0.5$$

$$495{,}456 \text{ KWH} \times 0.005 \text{ \$/KWH} = 2477 = \$2{,}500/\text{Yr.}$$

7.3 The Selling Price per Home and the Monthly Payment

The Revenue requirements approach is used in order to determine the selling price per home. The following calculations deal with the production operation for the plant.

Assumptions are made:

(1) Project life is assumed to be five years;

(2) Straight line depreciation is used as CCA (Capital Cost Allowance) or depreciation;

(3) MARR (Minimum Attractive Rate of Return) is assumed to be twenty percent after tax;

(4) Income tax is assumed to be fifty percent; and

(5) The project is financed by one hundred percent equity capital. The income tax factor ϕ, therefore, is calculated as follows:

$$\phi = \frac{t}{1-t}\left(1 - r\frac{i_d}{i_c}\right) = \frac{0.5}{1 - 0.5}\left(1 - 0 \times \frac{i_d}{i_c}\right) = 1$$

Total first cost consists of the cost of the equipment including the installation cost, the building, the land and the working capital. The summary of first costs, salvage values and depreciation are given in Table 7.1.

Revenue Requirements

$$\text{ATCFR} = (\text{Total First Cost})\ (a/p)^{20\%}_{5\ \text{years}} - (\text{Net Salvage Value})\ (a/f)^{20\%}_{5\ \text{years}}$$

$$= 542{,}822 \times 0.33438 - 399{,}286 \times 0.13438$$

$$= 181{,}509 \quad - 53{,}656$$

$$= 127{,}853$$

$$\text{IT} = \phi\ (\text{ATCFR} - \text{AEDE})$$

$$= 1\ (127{,}853 - 28{,}708)$$

$$= 99{,}145$$

Operating Cost = 1,266,570

Revenue Required = 127,853 + 99,145 + 1,266,570

= 1,493,568

Selling price per home (panels only, excluding floor tiles, carpet, roofing, ceiling, servicing facilities)

$$\frac{\$1{,}493{,}568}{500\ \text{homes}} = \$2987/\text{home}$$

$$= \$1.925/\text{sq. ft.}$$

It is assumed that these dwellings are sold through real estate companies paying seven percent of the selling price of the dwellings as the commission. It is, therefore, estimated that ten percent of selling price of the dwellings is needed to take care of the total sales costs for the dwellings.

The total dwelling cost to determine the monthly payment of this particular dwelling is estimated as follows so that an evaluation can be made as to the suitability of this dwelling for the low-to-medium income families.

Description	Cost, $
(a) Panels	2,987
(b) Materials:	
(1) Floor system	
Floor tiles, vinyl asbestos 12" x 12"	
Kitchen 36 sq. ft.	
Bedroom 96 sq. ft.	
Hallway 112 sq. ft.	
Bathroom 36 sq. ft.	
Dinette 48 sq. ft.	
328 sq. ft. @ $0.32/sq. ft.	105
(installation cost included)	
Carpet, nylon pile	
Master's bedroom 144 sq. ft.	
Living room 172 sq. ft.	
316 sq. ft. @ $1.00/sq. ft.	316
(installation cost included)	
Floor, fir plywood	611
(2) Roof System	
Trusses	325
Roof, plywood sheathing	465
Roofing (installed) @ $17/100 sq. ft. x 720 sq. ft.	123
(3) Ceiling system	
Ceiling (installed) @ $27/100 sq. ft. x 720 sq.ft.	195

Description		Cost, $
(4) Servicing facilities system		
Servicing facilities (See Table 4.2)		2,758
(5) Foundation system		
Concrete basement with joist		
@ $3/sq. ft. x 720 sq. ft.		2,160
(c) Connection blocks for locking mechanisms		
(8' - 0") x $\frac{105''}{12}$ x @ 2.25/sq. ft.		158
(d) Erection		1,000
(e) Land 50' x 110' average land cost		6,000
(obtained from Statistics of Canada)		
	Total	$17,203
Sales cost 10% of the total		1,720
	Grand Total	$18,923

Assuming that present price trends will continue over the next three years the comparative cost of a FLEXI-GROW home purchased in 1974 by a low-to-medium income family versus a conventional home purchased in the same year is outlined in Table 7.4 based on the following assumptions:

(1) The basic floor plan of 720 square feet will be expanded to 960 square feet in three years time;

(2) The estimated cost of the expansion will be $11.58 per square foot based on a 5 percent growth in building costs;

(3) The building and land cost for conventional building were estimated as follows:

Building *\$20/sq.ft. x 960 sq.ft.	=	\$19,200
Land, [illegible] ft. x [illegible] ft.		**\$ 6,000
Profit for contractors and real estate firms (estimated)		\$ 5,000
	TOTAL	\$30,200

(4) Mortgage rates are 10 percent;

(5) Payment term is 25 years; and

(6) The same low initial down payment is used under each plan for comparative purposes.

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* \$20/sq.ft. for building cost in January 1974, obtained from Alberta Housing Corporation.

** According to statistics of Canada.

Table 7.4 Comparative Costs of a FLEXI-GROW Home Versus a Conventionally Built Home

Year	Remarks	Payment	
		FLEXI-GROW Home $	Conventional Home $
1974	Initial cost	18,923.00	30,200.00
1974	Down payment	1,000.00	1,000.00
	Monthly payment at 10% interest over 25 years	143.39	233.60
1977	240 square feet addition @ $11.58/sq.ft. (960 square feet of living area)	2,779.20	
1977	Additional monthly payment	25.46	
	Total monthly payment	168.85	

Table 7.4 indicates that the monthly payment for a FLEXI-GROW home is more reasonable than that of a conventional home. This approach offers one feasible solution to produce dwellings to the low-to-medium income families.

CHAPTER VIII

SUMMARY AND CONCLUSION

The objective of this study was to develop and design a system of producing a functional home that is marketable and reasonable in price for the low-to-medium income family. The FLEXI-GROW housing system was selected as the chosen system for its flexibility to change the floor plan as desired and the minimum initial investment required.

For the low-to-medium income families, a low down payment and relatively low monthly payments in the initial years are normally essential when purchasing a home. The dwelling being studied can be purchased with monthly payments of approximately one hundred and seventy dollars based on a one thousand dollar down payment.

The cost data used is based on the specified items or materials required in order to come up with reasonably accurate cost estimates.

The on-site erection time should not take more than seven days and requires a minimum number of experienced tradesmen. The expansion of the dwelling may be accomplished as easy as the original erection.

The manufacturing system has the flexibility to produce panels of varying length where desired and to increase the production rate when demanded. A special effort was made to keep variations in panel sizes to a minimum in order to reduce

manufacturing and erection costs. The chosen system utilizes panels that are load bearing.

An in depth study has not been conducted at this stage with respect to the market demand for this housing system. However, rising costs of conventional materials and on-site manpower should be in favor of factory production becoming more viable in future years.

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APPENDIX A

POSSIBLE ALTERNATIVE FLOOR PLAN

The figure is provided in the pocket at the back of the bound thesis

APPENDIX B

FIGURES OF THE PANELS DESIGNED AND SUMMARY TABLE OF PANELS

Coding

The panel model numbers used are coded in the following manner:

Use
- E: exterior wall panel
- I: interior wall panel
- ST: exterior side triangular wall panel

Approximate wall panel length

E - 15 - W1 - D1

Door
- D1: door (2'-6"x6'-8")
- D2: door (2'-6"x6'-8") The door location is different than D1.
- SD: sliding door

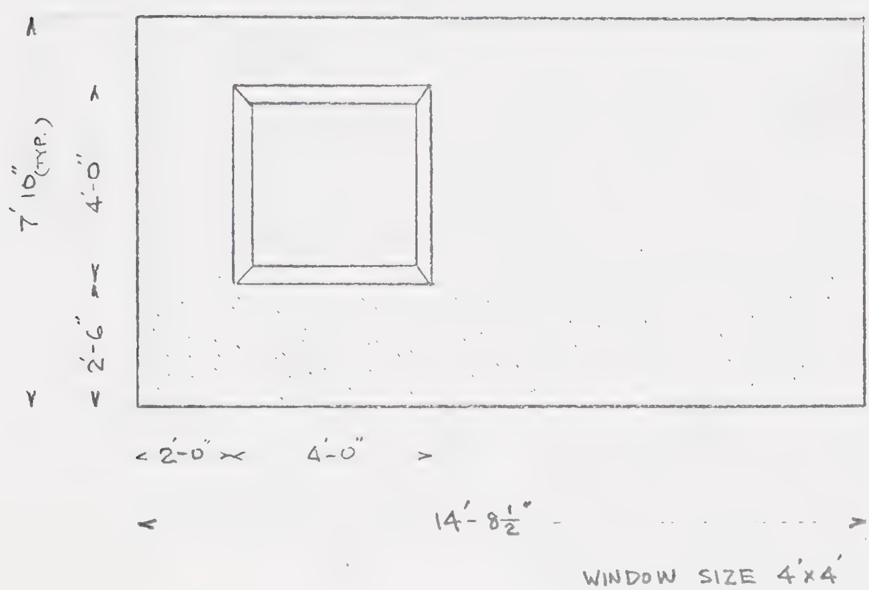
Window
- W1: 6'x4'
- W2: 4'x4'
- W3: 2'-6"x4'

TABLE B.1 SUMMARY TABLE OF PANELS

PANEL MODEL NO.	LENGTH	WINDOW SIZE	DOOR SIZE	NO. REQ'D PER HOME 720 SQ FT	960 SQ FT	1200 SQ FT
E-15-W1-D1	14'-8½"	6'× 4'	2'-6"× 6'-8"	1		
E-15-W1	14'-8½"	6'× 4'		1		
E-15-W2	14'-8½"	4'× 4'		1		
E-15-W3	14'-8½"	2'-6"× 4'		1		
E-12-W2-D1	11'-8"	4'× 4'	2'-6"× 6'-8"	1		
E-12	11'-8"			3		2
E-10-W2	9'-8"	4'× 4'			2	1
E-10-SD	9'-8"		6'-0"× 6'-8"			1
I-12-D1	12'-0"		2'-6"× 6'-8"	2		1
I-12-D2	12'-0"		2'-6"× 6'-8"		1	
I-12	12'-0"			1	1	
I-10-D1	9'-6"		2'-6"× 6'-8"		1	
I-10	9'-6"				1	
I-9-D1	8'-6"		2'-6"× 6'-8"		1	
I-9	8'-6"			1		
I-8	7'-9½"			1		
I-6-D1	5'-6"		2'-6"× 6'-8"	1		
I-4	4'-0"			4		
I-2	2'-0"			3	1	1
ST-12				4		2

THICKNESS 3 IN (TYP.)
HEIGHT 7'-10" (TYP.)

PANEL E-15-W2



PANEL E-15-W3

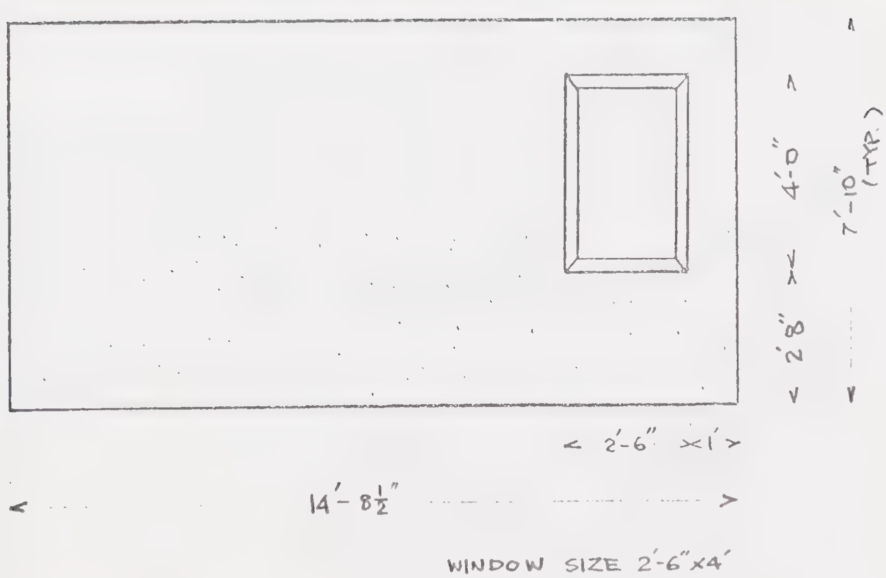
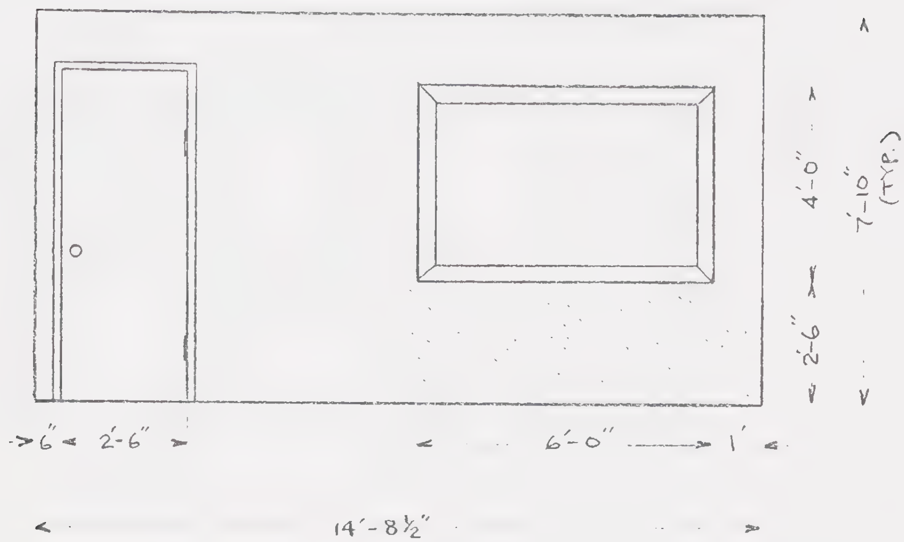


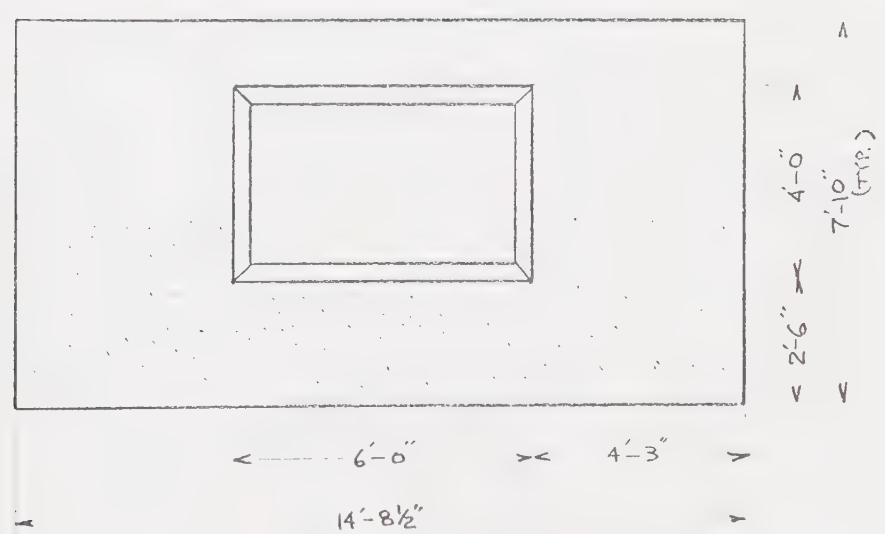
FIGURE B1 THE PANELS DESIGNED

PANEL E-15-W1-D1



WINDOW SIZE 6'x4'
DOOR SIZE 2'-6"x6'-8"

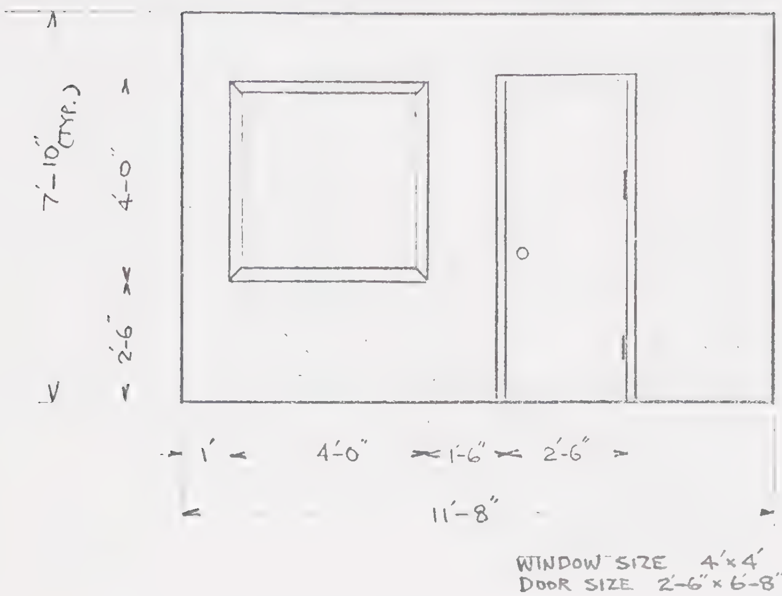
PANEL E-15-W1



WINDOW SIZE 6'x4'

FIGURE B.1 CONTINUED

PANEL E-12-W2-D1



PANEL E-10-W2

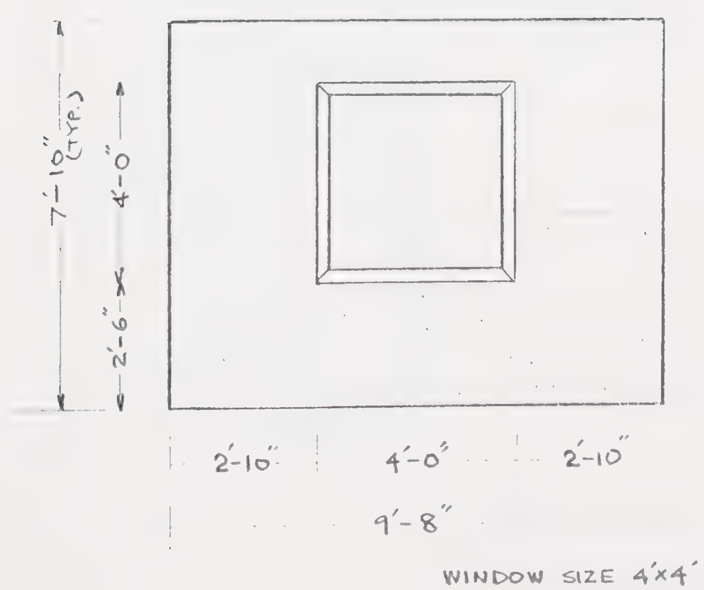
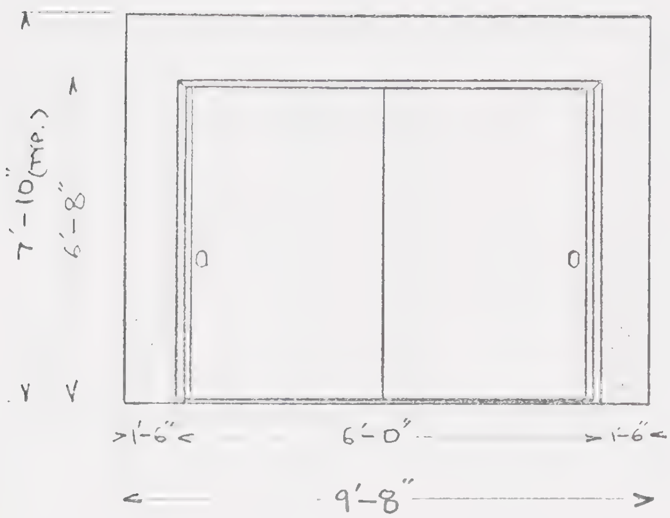


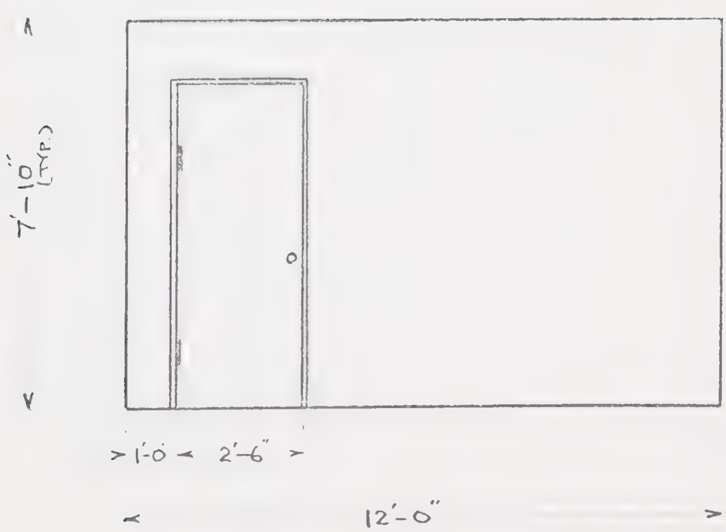
FIGURE B.1 CONTINUED

PANEL E-10-SD



SLIDE DOOR SIZE 6'-0" x 6'-8"

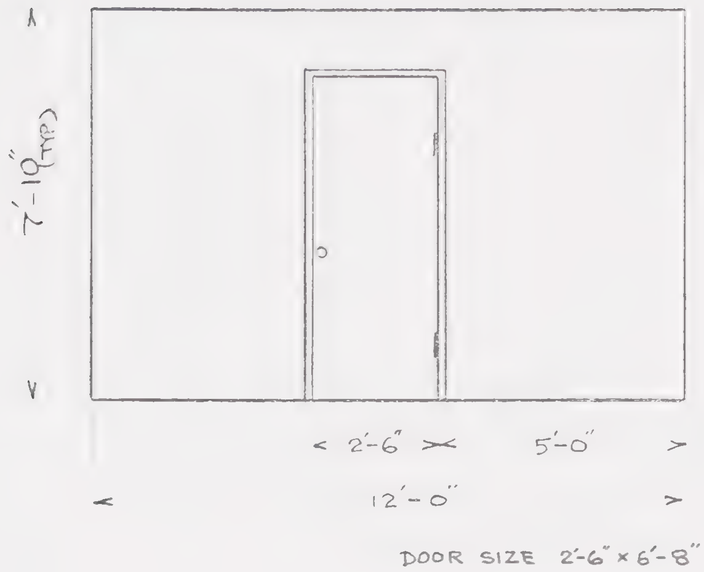
PANEL I-12-D1



DOOR SIZE 2'-6" x 6'-8"

FIGURE B.1 CONTINUED

PANEL I-12-D2



PANEL I-10-D1

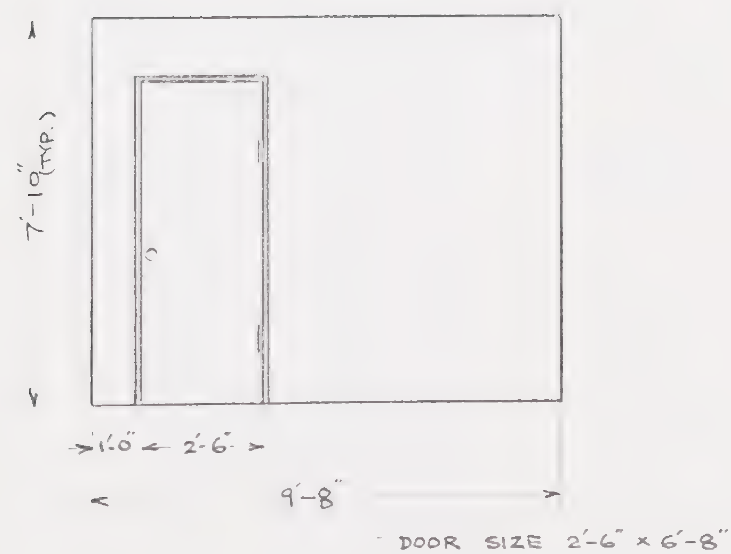
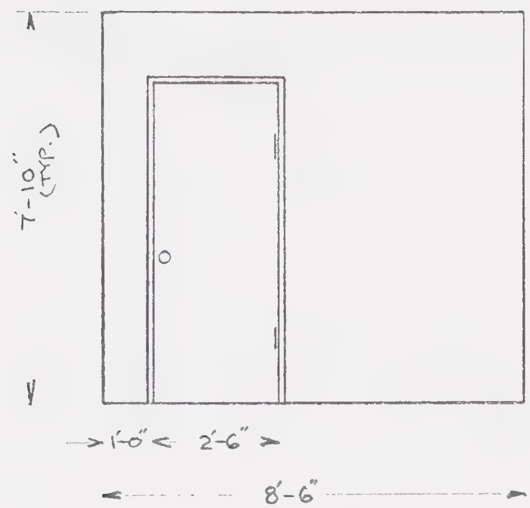


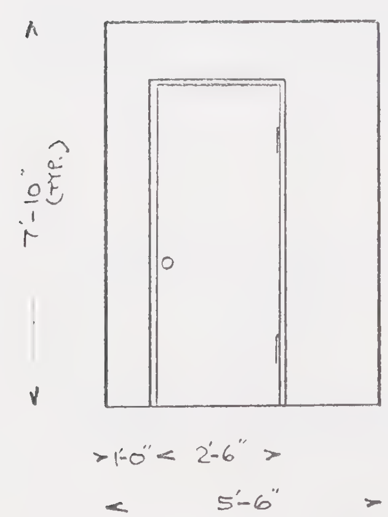
FIGURE B1 CONTINUED

PANEL I-9-D1



DOOR SIZE 2'-6" x 6'-8"

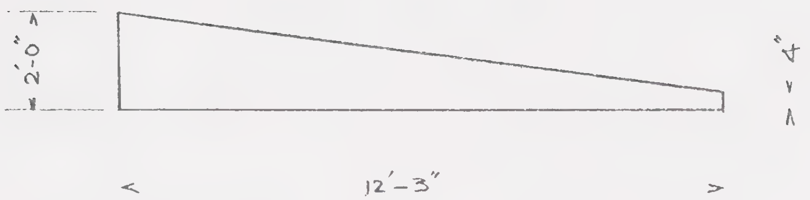
PANEL I-6-D1



DOOR SIZE 2'-6" x 6'-8"

FIGURE B.1 CONTINUED

PANEL ST-12



TYPICAL EDGE PREPARATION FOR
INTERIOR & EXTERIOR WALL PANEL

CONNECTION BLOCK

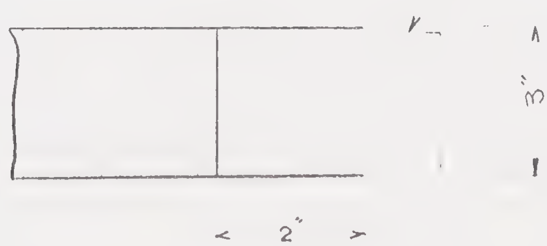


FIGURE B.1 CONTINUED

APPENDIX C

SERVICE FACILITIES

The following equipment may be installed in the dwelling.

(1) Carrier Standard Weathermaker (option)

Model 38 GC

(2) Carrier Humidifier, evaporative type (option)

Model 49BA001

Operating weight	20 lbs.
Supply water line	1/4" OD copper tubing, maximum length 20 ft.
Jet pump capacity (gal/hr)	
Primary flow	3.45
Minimum total flow	12.0
Dimensions	
Height	1'-7-7/8"
Length	1'-4-1/2"
Width	9-1/2"

(3) Carrier Evaporator Coils (option)

Model 28AE004

Coil face area (sq. ft)	2.77
Coil rows (fins/in)	3/12
Air quantity, (cfm)	
Nominal	1200
Range	900-1500
Maximum downflow	1320
Dimensions	(1'-3-7/8") x (1'-7") x (1'-2-1/8")

(4) Carrier Air Cleaners (option)

Model 31MA012	
Operating weight (lbs)	50
Air quantity (cfm)	600-1200
Dimensions	29-5/8" x 8-9/16" x 24-5/16"

(5) Crane FUTURA, prefabricated bathroom (option)

Model	200
Shipping weight (lbs)	500
Crate size	(5'-2")x(5'-9") x (3'-4")
Lavatory supply	4"
Centers	1-1/4"
Waste and overflow	1-1/2"

APPENDIX D

THE EQUIPMENT SPECIFICATIONS

Honeycomb expander and curer

Manufacturer	Union Camp Corporation 1600 Valley Road, Wayne, N.J. U.S.A.
Thickness of core capable	1/2" - 4"
Width of core capable	up to 56"
Weight	7,800 lbs.
Operation speed	6 ft. ∿ 10 ft/minute

Uncoiler

Manufacturer	Elkhart Welding & Boiler Works, Inc. 2132 South Main Street, Elkhart, Indiana U.S.A.
Model	J 481
Capacity	100,000 lbs.
Drive	Motor driven, 1.5 KW
Weight	1,000 lbs.
Height	4'-0"
Width	4'-0"
Length	4'-0"

Lock-former

Manufacturer	General Metal Machinery Ltd. 10820 - 119 Street, Edmonton, Alberta
Capacity	Maximum 20 gauge steel
Weight	500 lbs.
Height	3'-0"
Width	4'-0"
Length	8'-0"

Lock-former (continued)

Motor	0.75 KW

Foam curing conveyor

Supplier	Coutts Machinery Company Ltd. 9119 Stadium Road, Edmonton, Alberta
Weight	1,500 lbs.
Height	6'-0"
Length	10'-0"
Width	9'-0"
Motor	1.5 KW

Foaming machine

Manufacturer	Unifoam Incorporated P.O. Box 2721 Station B, Toledo, Ohio U.S.A.
Distributor	API Systems 11034 Sutter Avenue Pacoima, California, U.S.A.
Model number	510
Output per minute	4 $\sim$ 12 pounds
Weight	1,000 lbs.
Height	3'-0"
Length	4'-0"
Width	3'-0"

Equipped with:

(1) Froth package assembly

(2) Pump speed tachometers

(3) Automatic purge

(4) Additional hose, 50 ft.

(5) Pressure Tank assembly

(6) Heating and cooling system

(7) Solvent drum pump

(8) Material drum pumps - two.

Slitter

Frication saw, heavy duty, industrial use accompanied by a jig.

Motor	0.5 KW

Pebble pattern roll former

Manufacturer	General Metal Machinery Ltd. 10820 - 119 Street, Edmonton, Alberta
Capacity	Maximum 20 gauge steel
Weight	500 lbs.
Height	3'-0"
Length	8'-0"
Width	4'-0"
Motor	0.75 KW

Roller conveyor, partially motorized

Supplier	Coutts Machinery Company Ltd. 9119 Stadium Road, Edmonton, Alberta
Weight	27,000 lbs.
Height	2'-6"
Length	91 ft. in total
Width	8'-6"
Motor	0.5 KW 20 motors required

Glue applicator

Supplier	Coutts Machinery Company Ltd. 9119 Stadium Road, Edmonton, Alberta
Tank capacity	50 gallon
Glue depositor	1-1/2" dia. x 8'-6"
Roll	3" dia. x 8'-6"

Circular saw

Heavy duty, industrial saw

Motor	0.5 KW

Crane

Manufacturer	Canadian Monorail Company
Distributor	Farwil Corporation 10441 - 123 Streee Edmonton, Alberta

Type	Overhead	Overhead
Capacity	5 tons	3 tons
Span	35 feet	35 feet
Motor	5 H.P.	3 H.P.
Electric control device	equipped	equipped

APPENDIX E

THE PLANT LAYOUT

The figure is provided

in the back of the bound thesis

APPENDIX F

ALTERNATIVE WALL CONNECTIONS STUDIES

The following connections were developed as the alternative wall connections:

(1) Corner connection for exterior wall panels;

(2) Corner connection for interior wall panels;

(3) "T" connection for exterior wall panels;

(4) "T" connection for interior wall panels;

(5) Straight connection for exterior wall panels; and

(6) Straight connection for interior wall panels.

F.1 The Corner Connection for Exterior Wall Panels

The corner connection for exterior wall panels is shown in Figure F.1. This is the connection method to joint two exterior wall panels at a corner.

F.2 The Corner Connection for Interior Wall Panels

Figure F.2 shows the corner connection for interior wall panels. This connection mthod is used to connect two interior wall panels at right angles.

F.3 "T" Connection for Exterior Wall Panels

Figure F.3 describes the detail of the "T" connection for exterior wall panels. As it is self-explanatory, three walls, two exterior wall panels and one interior wall panel, are connected like T letter.

F.4 "T" Connection for Interior Wall Panels

This connection method is shown in Figure F.4. This method is used to joint two interior wall panels or three interior wall panels like T letter.

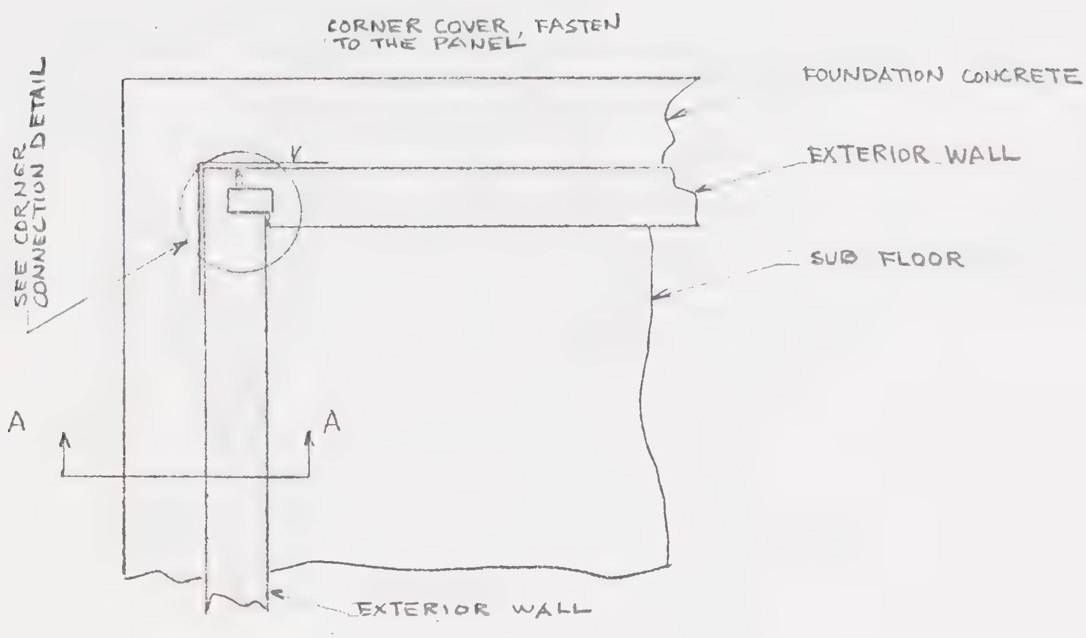
F.5 The Straight Connection for Exterior Wall Panels

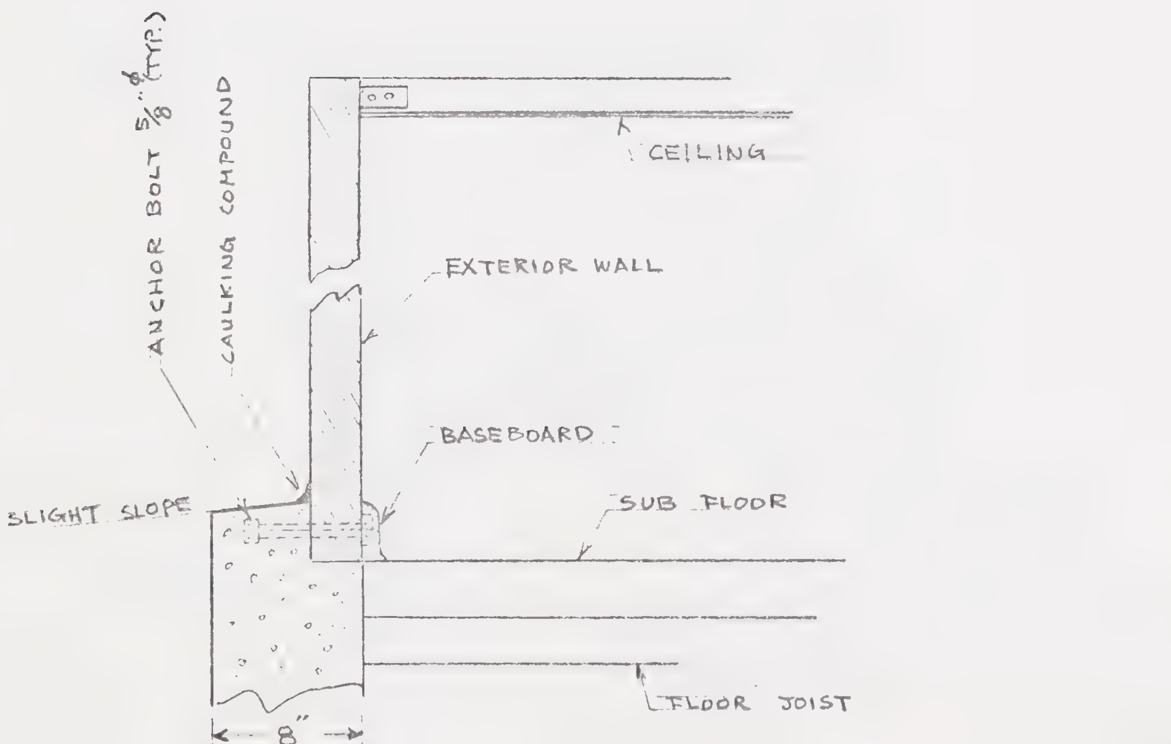
Figure F.5 shows two exterior wall panels to be connected straight. This connection method will be used in the extension of the master's bedroom in expansion one.

F.6 The Straight Connection for Interior Wall Panels

This connection method will be used to connect two interior wall panels straight. The detail of the connection is shown in Figure F.6.

CORNER PLAN VIEW

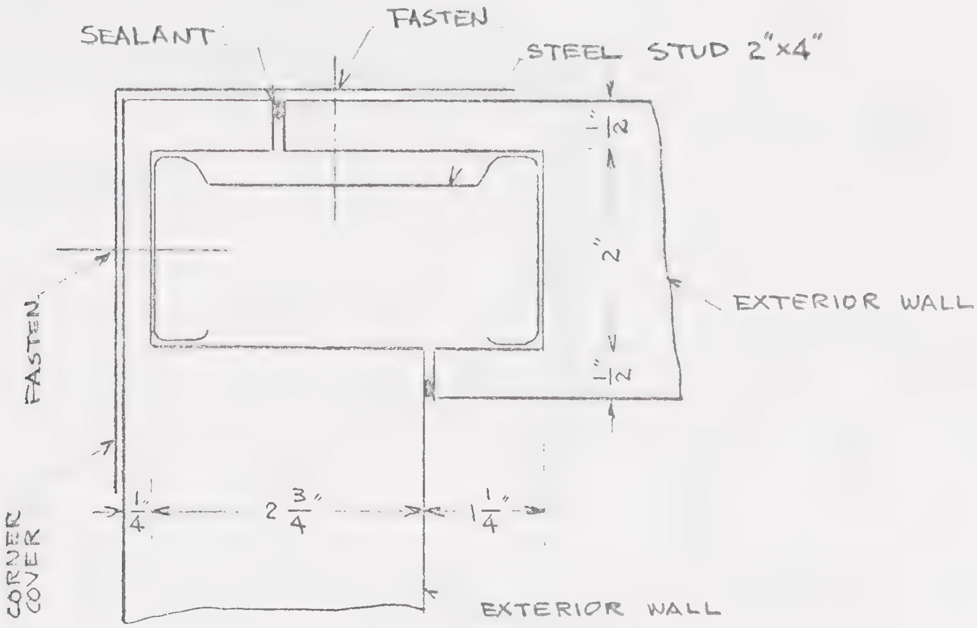




SECTION A-A

FIGURE F.1 THE CORNER CONNECTION FOR EXTERIOR WALL PANELS

CORNER CONNECTION DETAIL



CORNER CONNECTION DETAIL FOR EXPANSION TWO

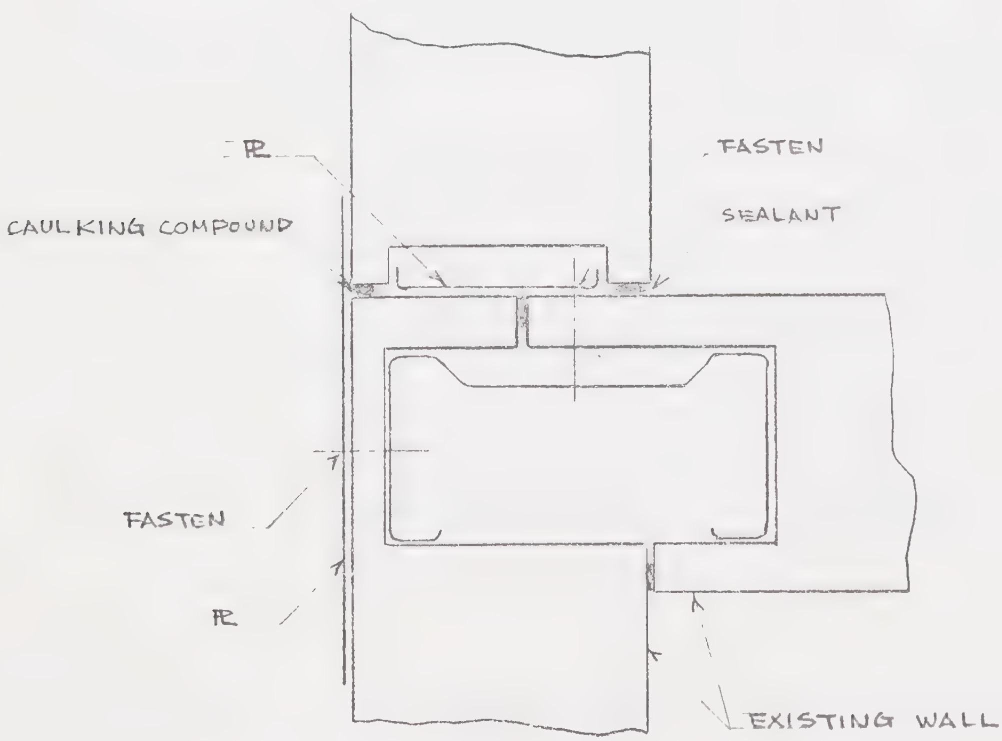


FIGURE F.1 CONTINUED

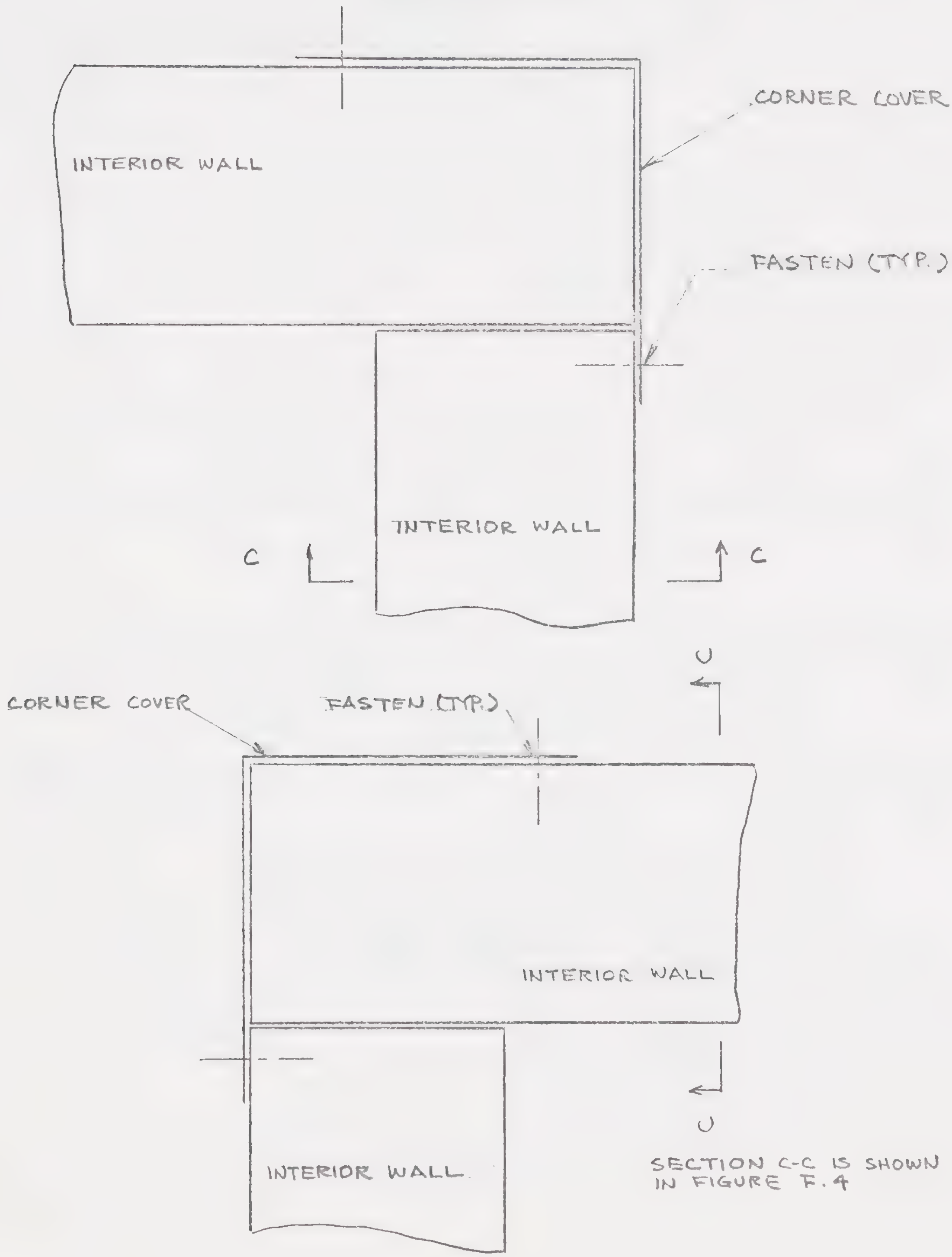
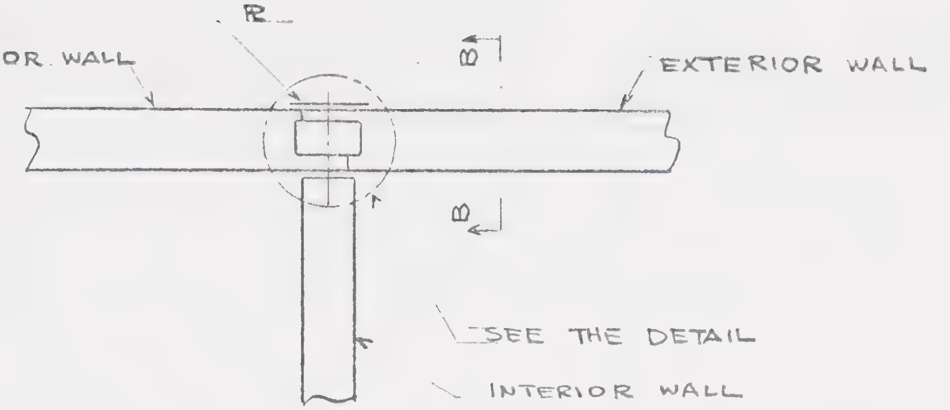


FIGURE F. 2 THE CORNER CONNECTION FOR INTERIOR WALL PANELS



"T" CONNECTION DETAIL FOR EXTERIOR WALL PANELS

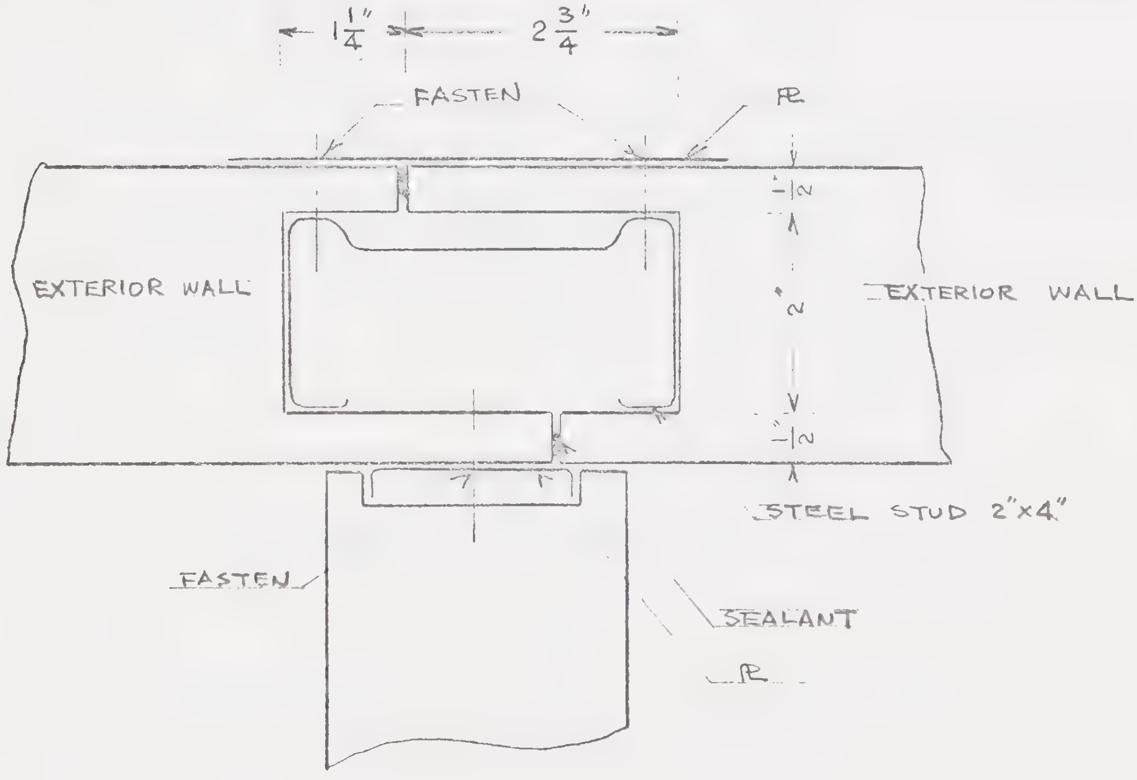


FIGURE F.3 THE "T" CONNECTION FOR EXTERIOR WALL PANELS

"T" CONNECTION DETAIL FOR EXPANSION TWO

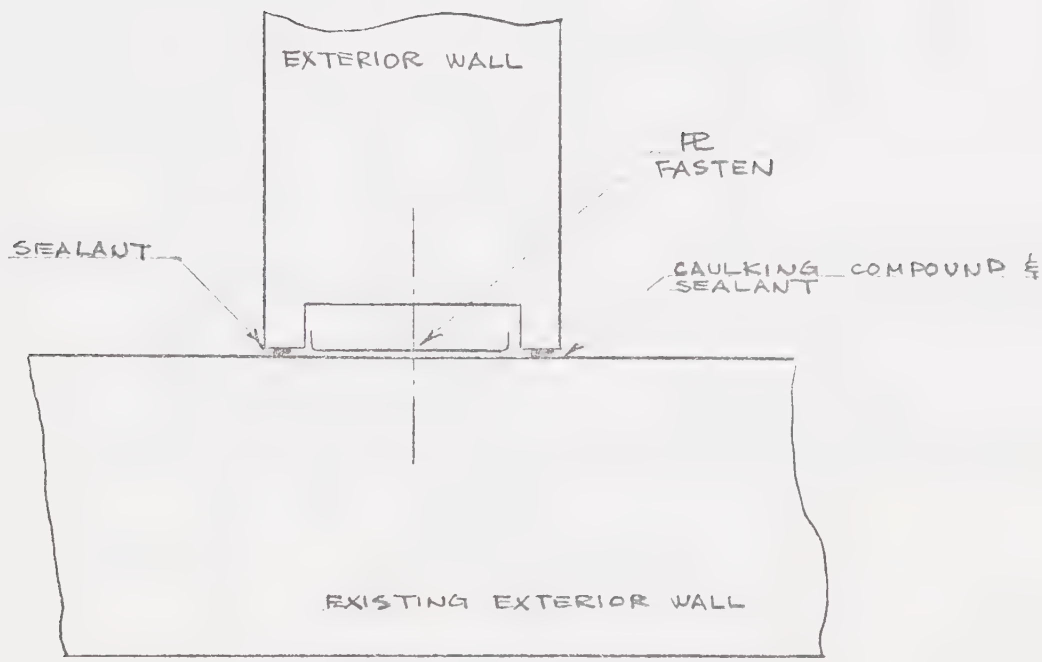
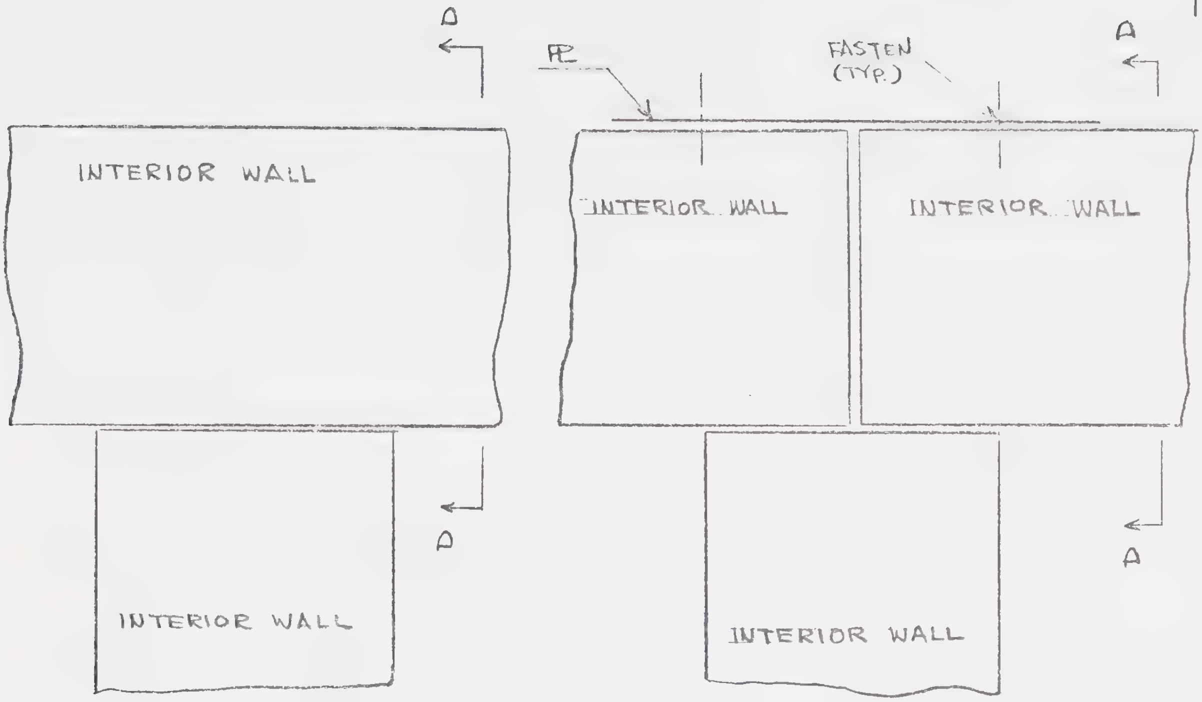
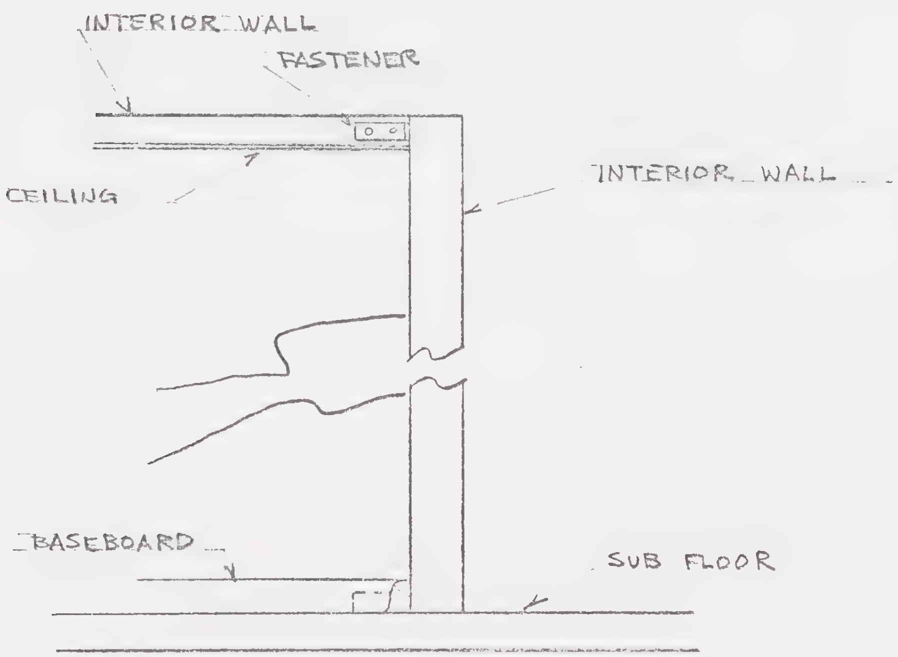


FIGURE F.3 CONTINUED





SECTION D-D

FIGURE F.4 THE "T" CONNECTION FOR INTERIOR WALL PANELS

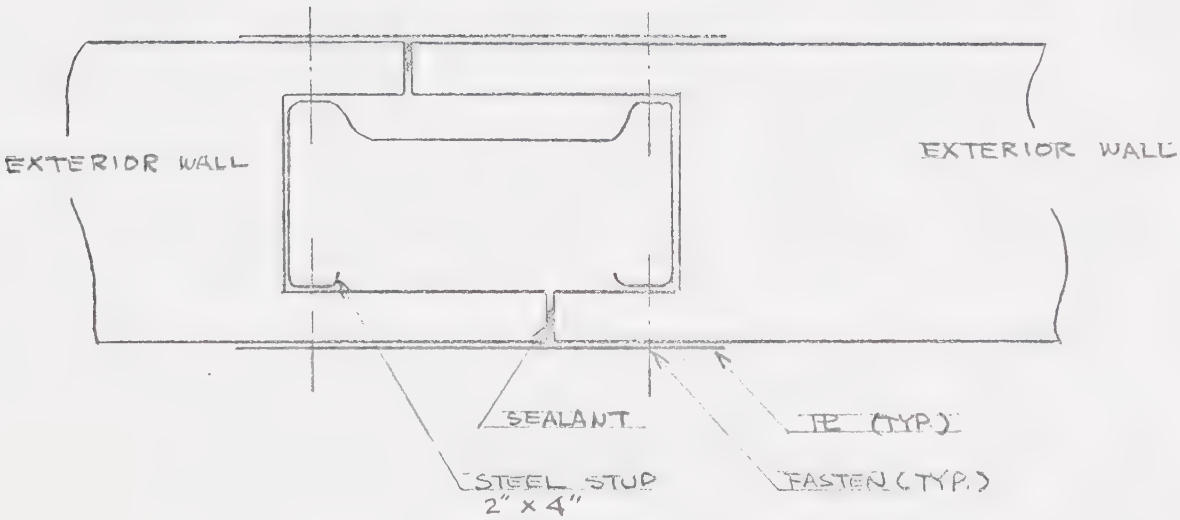
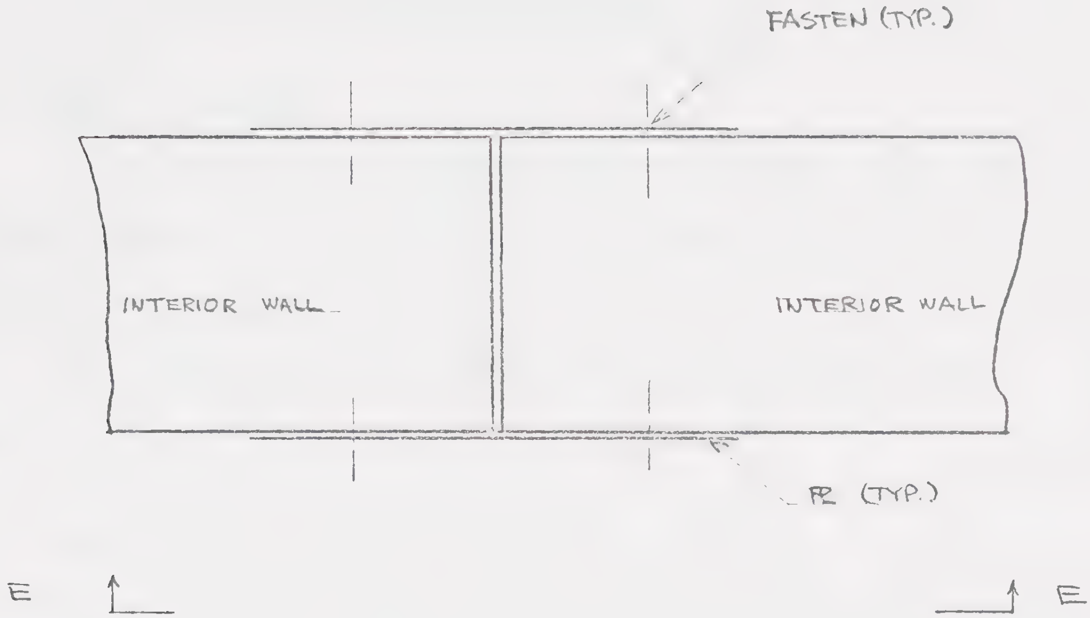
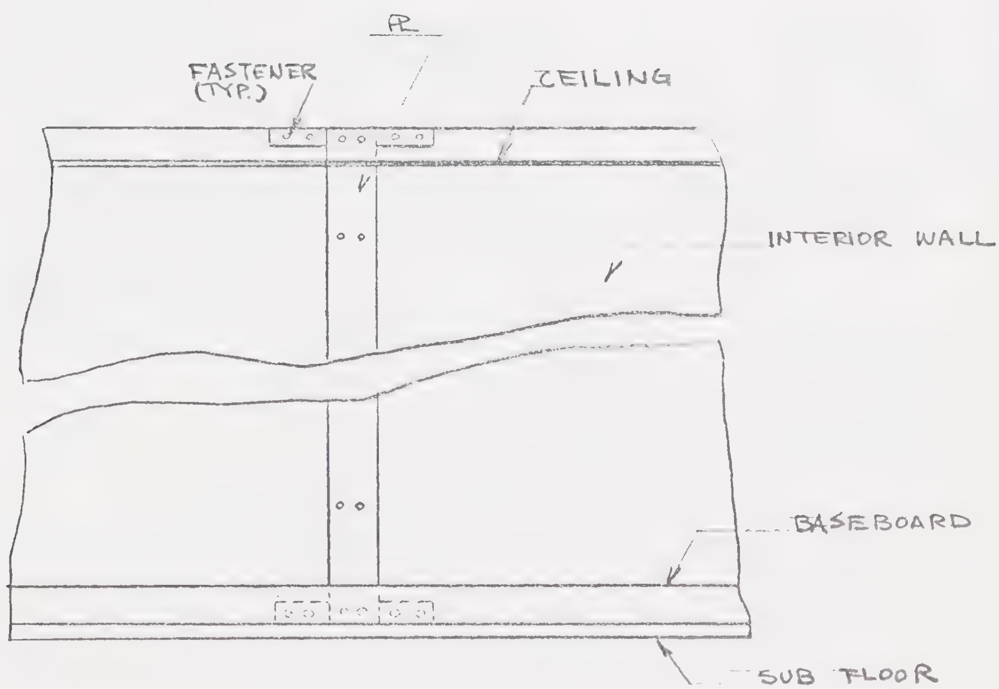


FIGURE F.5 THE STRAIGHT CONNECTION FOR EXTERIOR WALL PANELS





SECTION E-E . . . N.T.S

FIGURE F.6 THE STRAIGHT CONNECTION FOR INTERIOR WALL PANELS

APPENDIX G

THE LOAD CALCULATION

G.1 Load Calculation

In order to design the panel which is the main component of this dwelling, the load applying to the panel has to be determined.

The following calculations are based on 720 square feet, (30' x 24') home.

G.2 Roof Load

(1) Dead load of the roof

Roof sheathing

1.1 lbs/sq. ft. x (34'x14.5') x 2	1,085 lbs.

Truss

2.65 lbs/board feet x $\frac{(2"x4")}{12}$ x 69 ft. req'd x 14 ea.	1,707 lbs.

Roof material

2.15 lbs/sq. ft. x (34'x14.5') x 2	2,120 lbs.
Total	4,912 lbs.

(2) Snow load and wind load

$S = C_s \times q$

where S: design snow load

q: ground snow load
Edmonton 27 psf
Calgary 19 psf
27 psf is chosen for calculation

C_s: snow load coefficient

$$C_s = 1.25(0.8 - \frac{18.5 - 30}{50})$$
$$= 1.25\ (0.8 + 0.23)$$
$$= 1.3$$

$S = 1.3 \times 27$ psf $= 35.1$ psf.

G.3 Total Snow Load

Total snow load = 35.1 psf x 986 ft.^{2} (roof area)

= 34,609 lbs.

If the roofs are exposed to the wind, the value of C_x is reduced by 25%, that is, total snow load would be 34,609 lbs. x 0.75 = 25,957 lbs.

G.4 Wind Load

$$p = q \cdot C_e \cdot C_g \cdot C_p \qquad [12]$$

where p: design external pressure

q: reference velocity pressure

location; Edmonton 10.7 psf

Calgary 11.3 psf

C_e: exposure factor, 1.0.

C_g: gust effect factor, 2.5.

C_p: external pressure coefficient 0.7.

$p = 11.3$ psf $\times 1.0 \times 2.5 \times 0.7 = 19.78$ psf (on the vertical surface).

The pressure on the roof which has the slope 2/12:

$$p' = 19.78 \text{ psf} \times \frac{14 \text{ psf*}}{40 \text{ psf}} = 6.92 \text{ psf.}$$

Total wind effect on the roof:

$$6.92 \text{ psf} \times \frac{986 \text{ ft}^2}{2} = 3{,}412 \text{ lbs.}$$

G.5 Total Load of Snow and Wind

Total load of snow and wind

= Snow load + Wind load

= 25,957 lbs. + 3,412 lbs. = 29,369 lbs.

This is less than the maximum snow load,

34,609 lbs., therefore 34,609 lbs. is chosen.

G.6 Total Roof Load

Total load of roof

= Dead load + Snow and Wind Load

= 4,912 + 34,609

= 39,512 lbs.

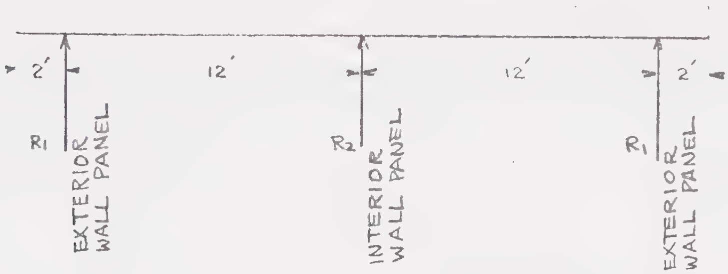
$$= \frac{39{,}512}{2200} = 17.96 \text{ tons.}$$

---

* See page 310 of [18].

G.7 Load Distribution on the Center Interior Wall and Exterior Wall

39,512 lbs/28 ft = 1,411 lbs/ft



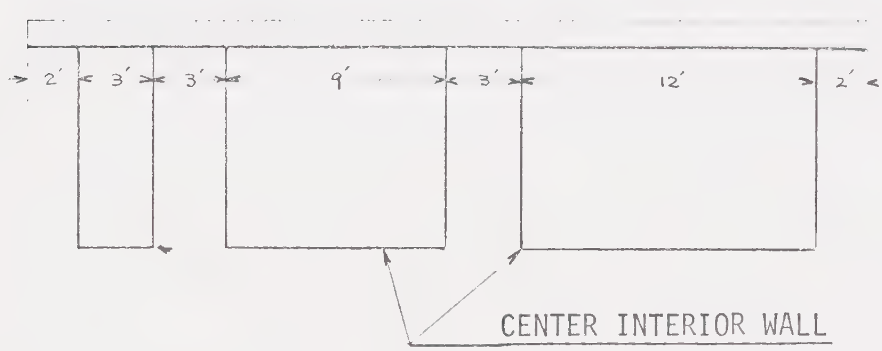
$$R_2 = \left(\frac{5}{8} + \frac{5}{8}\right)^{*} \times 1{,}411 \text{ lbs/ft} \times 12 \text{ ft.}$$

$$- (2 \times 1 \times 1{,}411 \text{ lbs/ft})/13 = 20{,}948 \text{ lbs.}$$

$$R_1 = (28 \times 1{,}411 \text{ lbs/ft} - 20{,}948 \text{ lbs}) \times \frac{1}{2} = 9{,}280 \text{ lbs.}$$

G.8 Load on the Center Interior Wall

20,948 lbs/34 ft = 616 lbs/ft.



Force applying on the center interior wall

= 20,948 lbs/(12 + 9 + 3)ft. = 873 lbs/ft.

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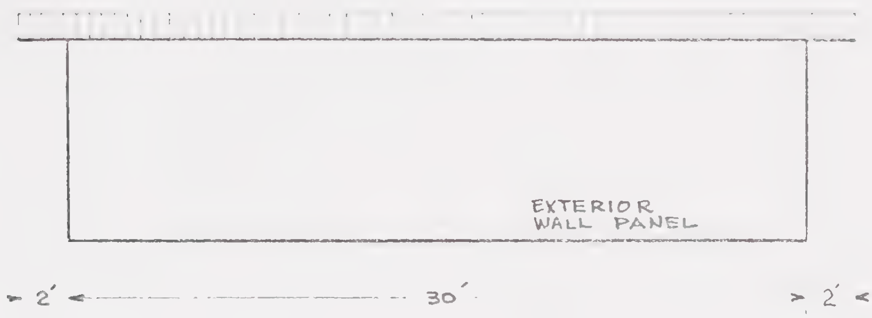
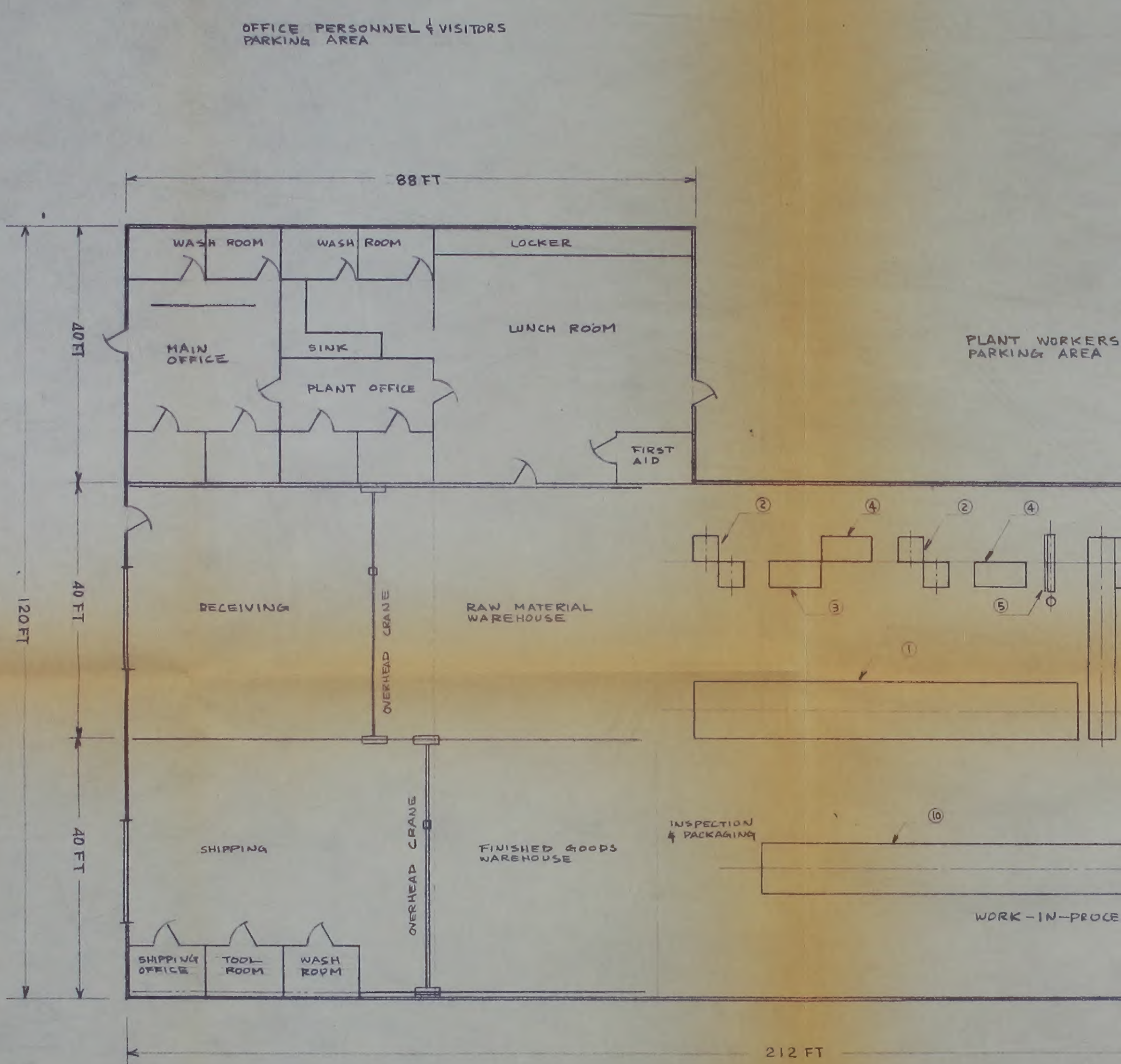
* See the page at 442 of Mechanical Engineers "Handbook", fifth edition, 1952, by L.S. Marks.

G.9 Load on the Exterior Wall

$$9{,}280 \text{ lbs}/30 \text{ ft} = 309 \text{ lbs/ft.}$$



The load of 873 lbs/ft. is chosen as the design load.



(1) HONEYCOMB EXPANDER & CURER
(2) UNCOILER
(3) ROLL FORMER FOR PEBBLE PATTERN
(4) LOCK FORMER
(5) GLUE APPLICATOR
(6) FOAMING MACHINE
(7) FOAM CURING CONVEYOR
(8) ROLLER CONVEYOR WITH A KICK OFF
(9) ROLLER CONVEYOR PARTIALLY MOTORIZED
(10) WORKING TABLE

MECHANICAL ENGINEERING DEPARTMENT
UNIVERSITY OF ALBERTA
H. HAYASHI

POSSIBLE ALTERNATIVE FLOOR PLAN
APPENDIX A

ENGINEER H. H.		SCALE 1/8" = 1'
JOB NO.	DRAWING NO. MECE 001	REV.